B.R. Wells

Arkansas Rice Research Studies 2022

J. Hardke, X. Sha, and N. Bateman, editors

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Cover Photo: Yeshi Wamishe discusses her rice plant pathology research and extension work while filming for the 2021 Arkansas Online Rice Field Day at the Rice Research and Extension Center in Stuttgart.

Photo credit: Nick Kordsmeier, director of communications for the Arkansas Agricultural Experiment Station, University of Arkansas System Division of Agriculture.

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Arkansas Agricultural Experiment Station (AAES), University of Arkansas System Division of Agriculture, Fayetteville. Deacue Fields, Vice President for Agriculture. Jean-François Meullenet, AAES Director and Senior Associate Vice-President for Agriculture–Research. WWW/CC2023.

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

DEDICATED IN MEMORY OF
Bobby R. Wells

Bobby R. Wells was born July 30, 1934, at Wickliffe, Kentucky. He received his B.S. degree in agriculture from Murray State University in 1959, his M.S. degree in agronomy from the University of Arkansas in 1961, and his Ph.D. in soils from the University of Missouri in 1964. Wells joined the faculty of the University of Arkansas in 1966 after two years as an assistant professor at Murray State University. He spent his first 16 years at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center near Stuttgart. In 1982, he moved to the University of Arkansas Department of Agronomy in Fayetteville.

Wells was a world-renowned expert on rice production with special emphasis in rice nutrition and soil fertility. He had a keen interest in designing studies to determine how the rice plant reacted to different cultural practices and nutrient supplementation: including timing and rates of nitrogen, phosphorus, and potassium fertilization; zinc fertilization of high pH soils; irrigation methods; dates and rates of seeding and the reasons for differing responses.

Wells was a major participant in the pioneering effort by University of Arkansas System Division of Agriculture scientists in the development of the Degree-Day 50 (DD50) computer rice production program which assists growers with 26 management decisions during the season based on temperature, rice cultivar, and growth stage; including herbicide application, critical times to scout and spray for insects and diseases, and nitrogen fertilizer application. The DD50 program developed in the 1970s remains a vital program to this day in assisting growers, consultants and extension agents in making important management decisions concerning inputs to optimize rice yield and quality. Other rice-growing states have followed suit in this important development and have copied the Arkansas DD50 program.

He was the principal developer of the nitrogen fertilizer application method known famously at the time as the Arkansas 3-way split application strategy; who his successor discovered, using the isotopic tracer N-15, to be the most efficient method (i.e., as concerns nitrogen uptake) of fertilizing rice with nitrogen in the world. The application method has since been modified to a 2-way split, because of the release of new short stature and semi-dwarf cultivars, but its foundation was built on Wells' 3-way split method.

Wells was a major participant in the development of cultivar-specific recommendations for getting optimum performance from new cultivars upon their release and reporting research results at Cooperative Extension Service meetings as well as in the Extension Service publications, even though he had no extension appointment; he just did what he thought was best for the Arkansas rice farmer. He made numerous presentations at annual meetings of the Tri-Societies and Rice Technical Working Group, published many journal articles, and several book chapters. He loved being a professor and was an outstanding teacher who taught a course in soil fertility and developed a course in rice production. Both courses are still being taught today by his successors. The rice production course he developed is the only rice production course being taught in the USA to the best of our knowledge.

Wells was very active in the Rice Technical Working Group (RTWG), for which he served on several committees, chaired and/or moderated Rice Culture sections at the meetings, and was a past secretary/program chair (1982-1984) and chairman (1984-1986) of the RTWG. He was appointed head of the Department of Agronomy (later renamed the Department of Crop, Soil, and Environmental Sciences) in 1993 and was promoted to the rank of University Professor that year in recognition of his outstanding contributions to research, teaching, and service.

Among the awards Wells received were the Outstanding Faculty Award from the Department of Agronomy (1981), the Distinguished Rice Research and/or Education Award from the Rice Technical Working Group (1988), and the Outstanding Researcher Award from the Arkansas Association of Cooperative Extension Specialists (1992). He was named a Fellow in the American Society of Agronomy (1993), and posthumously, the Distinguished Service Award from the RTWG (1998) and induction into the Arkansas Agriculture Hall of Fame (2017). Wells edited this series when it was titled Arkansas Rice Research Studies from the publication's inception in 1991 until his death in 1996. Because of Wells' contribution to rice research and this publication, it was renamed the B.R. Wells Rice Research Studies in his memory starting with the 1996 publication. The name of this publication was modified in 2014 to the B.R. Wells Arkansas Rice Research Studies.

FEATURED RICE COLLEAGUE

Yeshi Wamishe

As a young girl in Ethiopia, Yeshi Wamishe was not encouraged to go to school; yet she still found herself desiring to become a teacher. She recalls sitting in her fifth-grade social studies classroom and promising herself that she would achieve the highest level of education possible. She did that and more.

"I aspired for a teaching job, and I went beyond the school set-up addressing a very prominent audience—the farming community," Wamishe said.

Her journey to Arkansas and earning her doctorate—and eventually settling into her dream career—was not a straight path. It somewhat mimicked traversing a rice field with its ups and downs on levees and the toilsome terrain of thick, muddy water.

No matter the difficulties, Wamishe persevered and brought love and passion to working with producers and researching rice diseases each season.

A Look Back at Her Career

Wamishe retired from her nearly 12-year position as an extension rice pathologist in February 2023. She loves being part of the farming community and understands that "farming is a risky business, and these days crop production cost is so high." She said her motivation comes from her experience living in a developing nation that experienced starvation—"I knew what it meant when a crop fails. I used to pray for every field I visited while I was on this job."

She was happy and thankful for her job even though rice fields were not the most effortless workplaces. "The ups and downs on levees, the smell from murky water, the difficulty walking in the mud and water—sometimes falling in the muddy water—working under intense sun, working off hours, driving long days and more are physically and mentally demanding."

But Wamishe said that the producers and their associates, who work the fields for a living, worked harder than she did. "Compared with them, my involvements were minimal," she said.

Throughout her career, Wamishe studied various diseases that infect rice plants. Some of her research focused on common diseases that prevailed every season, but now and then, her research changed with the importance of observed field problems. With changes in weather, environmental conditions or field management, what was once a seemingly minor disease could wreak havoc on a field.

She worked closely with Rick Cartwright, retired director of the Arkansas Cooperative Extension Service, who taught her some tricks for in-field disease diagnosis, communicating with producers, giving presentations and more. Wamishe recalled being nervous about the shoes she would have to fill when she interviewed for the job, so she requested that Cartwright promise to be her mentor. "He turned out to be my mentor, teacher, advisor and friend like my big brother."

Early Life and College

Growing up, Wamishe worked on her family farm weeding; herding calves, sheep and goats; cutting flax and taking care of her mother's backyard vegetable garden. "In a farming family, children helped wherever and whenever needed."

Her home responsibilities broadened when she was a sophomore in college. Wamishe's father passed away and she took over the farm that season, for none of her brothers were around to help. The following season she farmed potatoes for the survival of her family.

"I could say, this was the turning point for me to understand what farming means and know its values," Wamishe said.

These instances did not prevent Wamishe from fulfilling her promise of educating herself and becoming an educator. She earned her bachelor's degree in biology in August 1979 and her master's degree in botany in July 1984, both from Addis Ababa University. As she reflects on these moments, she thinks "God saw the future. I wanted to be a teacher, and I became that and more to impact even better with the greater passion I developed after my father's death."

While earning those degrees, Wamishe said she also taught in schools. While she was an undergraduate student, she taught biology and chemistry in high schools and became a biology teacher to freshmen in college after graduating. When she earned her master's degree, she taught botany and plant pathology at the same college.

In 1986, she made her way to the International Center for Wheat and Maize Improvement in Obregon City, Mexico. While there, Wamishe was looking for ways to further her education and reach the highest level. Later, her teacher connected her to her Ph.D. advisor, and in 2002, Wamishe received her doctorate degree in plant science and plant pathology from the University of Arkansas.

After receiving her doctorate, she took positions as a post-doctoral research associate in Stuttgart studying rice diseases and at Clemson University to study diseases of ornamental crops. At Clemson, she worked for an extension plant pathologist. Soon after, she taught classes in junior colleges in Georgia and Mississippi. Throughout all of those jobs, she had ceaseless thoughts of working in farming.

Her time at Clemson University reaffirmed her interest in extension, she decided to search for a job in teaching, research and extension, and she found that job in Arkansas.

"Coming back to Arkansas with such a job was like a dream come true," Wamishe said. "I got reconnected to farm fields and producers. Besides, it was in Arkansas, in my school where I went for my doctorate. I felt a family environment and decided to stay until I retired."

When Wamishe reflects on her career, she remembers what one of her teachers told her: "I do not care where in the world you want to live, but I want you to do your best to benefit human nature."

"I took his advice seriously in the past and will sure dwell on it in the future," Wamishe said. "I pass the same advice to the current generations and the generations to come."

Brittaney Mann
University of Arkansas System Division of Agriculture Communications

FOREWORD

Research reports contained in this publication may represent preliminary or only a single year of results; therefore, these results should not be used as a basis for long-term recommendations.

Several research reports in this publication will appear in other Arkansas Agricultural Experiment Station publications. This duplication is the result of the overlap in research coverage between disciplines and our effort to inform Arkansas rice producers of all the research being conducted with funds from the rice check-off program. This publication also contains research funded by industry, federal, and state agencies.

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

ACKNOWLEDGMENTS

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The Arkansas Rice Research and Promotion Board

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Trends in Arkansas Rice Production, 2022

J.T. Hardke[1]

Abstract

Arkansas is the leading rice producer in the United States. The state represents 50.1% of total U.S. rice production and 49.8% of the total acres planted to rice in 2022. Rice cultural practices vary across the state and across the U.S. However, these practices are also dynamic and continue to evolve in response to changing political, environmental, and economic times. This survey was initiated in 2002 to monitor and record changes in the way Arkansas rice producers approach their livelihood. The survey was conducted by polling county extension agents in each of the counties in Arkansas that produce rice. Questions included topics such as tillage practices, water sources and irrigation methods, seeding methods, and precision leveling. Information from the University of Arkansas System Division of Agriculture DD50 Rice Management Program was included to summarize variety acreage distribution across Arkansas. Other data were obtained from the USDA National Agricultural Statistics Service.

Introduction

Arkansas is the leading rice producer in the United States in terms of acreage planted, acreage harvested, and total production. Each year, rice planting typically ranges from late March into early June with harvest occurring from late August to early November. Rice production occurs across a wide range of environments in the state. The diverse conditions under which rice is produced leads to variation in the adoption and utilization of different crop management practices. A survey was initiated in 2002 to record annual production practices in order to monitor and better understand changes in rice production practices, including adoption of new practices. Information obtained through this survey helps to illustrate the long-term evolution of cultural practices for rice production in Arkansas. It also serves to provide information to researchers and extension personnel about the ever-changing challenges facing Arkansas rice producers.

Procedures

A survey has been conducted annually since 2002 by polling county agriculture extension agents in each of the counties in Arkansas that produce rice. Questions were asked concerning topics such as tillage practices, water sources and irrigation methods, seeding methods, and precision leveling. Acreage, yield, and crop progress information was obtained from the USDA National Agricultural Statistics Service (http://www.nass.usda.gov). Rice cultivar distribution was obtained from summaries generated from the University of Arkansas System Division of Agriculture DD50 Rice Management Program enrollment.

Results and Discussion

Rice acreage by county is presented in Table 1 with distribution of the most widely-produced cultivars. RT 7521 FP was the most widely planted cultivar in 2022 at 29.8% of the acreage, followed by RT XP753 (17.8%), RT 7321 FP (14.6%), DG263L (10.9%), Diamond (5.5%), CLL16 (4.9%), Jupiter (4.5%), and Titan (2.7%). Additional cultivars of importance in 2022, though not shown in the table, were RT 7301, PVL03, ARoma 17, RT 7401, CLM04, and CLL15.

Arkansas planted 1,106,000 acres of rice in 2022 which accounted for 49.8% of the total U.S. rice acres (Table 2). The state-average yield of 7,410 lb/ac (164.7 bu./ac) represented a 220 lb/ac decrease compared to 2021. The 2021 yield of 7,630 lb/ac (169.6 bu./ac) was a state record. Regular early rainfall through April slowed planting progress compared to the 5-year average and progress did not achieve average pace until mid-May. Rainfall events largely ended along with the month of May. June and July were met with extreme heat and drought conditions. Weed control and irrigation efforts were strained throughout the summer months due to these conditions. Harvest progress slightly trailed the 5-year average through September. While rains did return as harvest approached, they largely disappeared once harvest began. The result was extremely favorable harvest weather throughout September and October with little rainfall, humidity, or dew to slow harvest. Overall milling yields were average, which was an improvement over 2021.

Final harvested acreage in 2022 totaled 1,084,000. The total rice produced in Arkansas during 2022 was 80.3 million hundredweight (cwt). This represents 50.1% of the 160.4 million cwt produced in the U.S. during 2022. Over the past three years, Arkansas has been responsible for 48.2% of all rice produced in the U.S. The largest rice-producing counties by acreage in Arkansas during 2022 included Lonoke, Jackson, Poinsett, Lawrence, Arkansas, and Clay, representing 41.9% of the state's total rice acreage (Table 1).

Planting in 2022 fell immediately behind the 5-year average beginning in March due to regular rainfall events (Fig. 1). Plant-

[1] Professor and Rice Extension Agronomist, Department of Crop, Soil, and Environmental Sciences, Rice Research and Extension Center, Stuttgart.

ing progress had reached only 4% by 10 April compared to 16% averaged across the previous 5 years. Planting progress improved only slightly throughout April. As of 1 May 40% of acres had been planted compared with an average of 59% by this date across the 5 previous seasons. By 5 June 98% of acres had been planted compared to the 5-year average of 96%. As harvest began, humidity remained low and conditions remained warm and dry. By 18 September harvest progress had reached 41% compared to 50% for the 5-year average (Fig. 2). About 75% of the crop had been harvested by 2 October compared with 76% harvest progress on the same date in previous years. Harvest progress was complete (100%) by 13 November.

Approximately 50% of the rice produced in Arkansas was planted using conventional tillage methods in 2022 (Table 3). This usually involves fall tillage when the weather cooperates, followed by spring tillage to prepare the seedbed. The remainder of rice acres is planted using stale seedbed (39.2%) or no-till (10.4%) systems. True no-till rice production is not common but is practiced in a few select regions of the state.

More rice is produced on silt loam soils (56.9%) than on any other soil texture (Table 3). Rice production on clay or clay loam soils (18.9% and 19.3%, respectively) has become static over recent years after steadily increasing through 2010. These differences in soil type present unique challenges in rice production such as tillage practices, seeding rates, fertilizer management, and irrigation.

Rice most commonly follows soybean in rotation, accounting for 66.9% of the rice acreage (Table 3). Approximately 20% of the acreage in 2022 was planted following rice, with the remainder made up of rotation with other crops including cotton, corn, grain sorghum, wheat, and fallow. The majority of the rice in Arkansas is produced in a dry-seeded, delayed-flood system with only 3.7% using a water-seeded system. Annually, approximately 85% of all the Arkansas rice acreage is drill-seeded with the remaining acreage broadcast-seeded (dry-seeded and water-seeded).

Irrigation water is one of the most precious resources for rice producers in Arkansas. Reports of diminishing supplies have prompted many producers to develop reservoir and/or tailwater recovery systems to reduce the "waste" by collecting all available water and re-using it. Simultaneously, producers have tried to implement other conservation techniques to preserve the resource vital to continued production. Groundwater is used to irrigate 78.7% of the rice acreage in Arkansas with the remaining 21.3% irrigated with surface water obtained from reservoirs or streams and bayous (Table 3).

During the mid-1990s, the University of Arkansas System Division of Agriculture began educating producers on multiple-inlet rice irrigation which uses poly-tubing as a means of irrigating rice to conserve water and labor. As of 2022, rice farmers utilize this practice on 28.9% of the rice acreage (Table 3). Most remaining acreage is still irrigated with conventional levee and gate systems. Intermittent flooding is another means of irrigation increasing in interest recently as a means to reduce pumping costs and water use; but the practice accounts for only 3.8% of acreage at this time. Additional interest has risen in growing rice in a furrow-irrigated system (row rice) as is common with soybean or corn as a means to simplify crop rotation and management and currently accounts for 18.0% of acreage compared to 20.2% and 16.9% in 2021 and 2020, respectively.

Stubble management is important for preparing fields for the next crop, particularly in rice following rice systems. Several approaches are utilized to manage the rice straw for the next crop, including tillage, burning, rolling, and winter flooding. In 2022, 49.4% of the acreage was burned, 47.7% was tilled, 27.5% was rolled, and 22.8% was winter flooded (Table 3). Combinations of these systems are used in many cases. For example, a significant amount of the acreage that is flooded during the winter for waterfowl will also be rolled. Some practices are inhibited by fall weather, and the wet fall weather from 2018 to 2020 resulted in a decrease in burning and tillage, but a subsequent rise in rolling and winter flooding.

Contour levee fields accounted for 53.0% of rice acres in 2022 (Table 3). Precision-leveled, or straight levee, fields represented 37.2% and zero-graded fields 9.8%. Each year growers attempt to make land improvements where possible to improve overall rice crop management, particularly related to water management. Modifying the slope, and subsequently the levee structure and arrangement in fields, can have a profound impact on the efficiency of rice production. Straight levee and zero-grade fields have been shown to significantly reduce water use in rice production in Arkansas.

The use of yield monitors at harvest (81.8%) and grid soil sampling (32.4%) have increased slightly in recent years (Table 3). However, only 17.4% of rice acres are fertilized using variable rate equipment. Urea stabilizers (products containing NBPT) are currently used on 88.7% of rice acres in Arkansas to limit nitrogen losses due to ammonia volatilization. The use of the Nitrogen Soil Test for Rice (N-STaR) remains low at 5.1% of acres, but additional tools are being developed to improve confidence and adoption of this practice. In addition, programs such as Pipe Planner, PHAUCET, and MIRI Rice Irrigation were used on 31.0% of rice acres in 2022. The use of a GreenSeeker handheld to monitor in-season nitrogen condition was utilized on 3.4% of acres. The use of cover crops in rice rotations remains limited, but it was a practice used on 5.7% of acres as wet fall periods the past few years have limited the implementation of cover crop programs in the state. Harvest aid applications, primarily sodium chlorate, are currently used on 37.3% of acres to improve harvest efficiency.

Pest management is vital to preserving both yield and quality in rice. Foliar fungicide applications were made on 58.5% of rice acres in 2022 (Table 3). Conditions were not as favorable for the development of disease during the 2022 season. Approximately 45% of rice acres received a foliar insecticide application due to rice stink bug infestation levels which were low to moderate overall. Insecticide seed treatments were used on 81.8% of rice acreage as producers continue to utilize this technology each year due to its early-season benefits for both insect control and improved plant growth and vigor.

The use of herbicide-tolerant rice cultivars continues to play a significant role in rice production in Arkansas. The technologies include Clearfield® (tolerant to imidazolinone herbicides), Full-Page™ (tolerant to imidazolinone herbicides), Provisia® (tolerant to ACCase herbicides), and MaxAce™ (tolerant to ACCase herbicides). Herbicide-tolerant cultivars (all technologies combined) accounted for 53% of the total rice acreage in 2022 (Fig. 3). It should be noted that insufficient data existed to include MaxAce acreage information and Provisia reporting was low, which if these were properly included would likely drive total herbicide-tolerant acres over 60%. Clearfield acres increased rapidly from 2001 to 2011 but have gradually declined since then. In 2018, Provisia became available on limited acres and in 2022 was planted on 1.5% of acres. FullPage, similar to Clearfield, was launched in 2020 and in 2022 was planted to 44.4% of acres. Acres of these and other herbicide technologies will likely increase in the coming years. Proper stewardship of these technologies will be the key to their continued success in rice. In areas where stewardship has been poor, imidazolinone-resistant barnyardgrass has been discovered.

Practical Applications

State average yields over the past 20 years in Arkansas have increased from an average of 140 bu./ac in 2000-2002 to an average of 167.0 bu./ac in 2020–2022, an increase of 27 bu./ac. This increase can be attributed to the development and adoption of more productive cultivars and improved management practices, including better herbicides, fungicides, and insecticides, improved water management through precision-leveling and multiple-inlet irrigation, improved fertilizer efficiency via timing and the use of urease inhibitors, and increased understanding of other practices such as seeding dates and tillage. Collecting this kind of information regarding rice production practices in Arkansas is important for researchers to understand the adoption of certain practices as well as to understand the challenges and limitations faced by producers in field situations.

Acknowledgments

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Table 1. 2022 Arkansas harvested rice acreage summary.

	Harvested Acreage[a]		Medium-Grain			Long-Grain						
County	**2021**	**2022**	**Jupiter**	**Titan**	**Others[b]**	**CLL16**	**DG263L**	**Diamond**	**RT 7321 FP**	**RT 7521 FP**	**RT XP753**	**Others[b]**
Arkansas	70,089	65,448	2,197	1,071	0	1,188	4,902	303	7,402	30,633	13,872	3,880
Ashley	7,968	4,563	0	0	0	913	0	0	0	2,282	1,369	0
Chicot	18,314	18,186	0	0	0	0	0	0	11,075	4,814	2,296	0
Clay	69,757	62,298	225	2,127	0	3,277	3,503	1,460	9,746	23,391	1,977	16,592
Craighead	61,454	50,276	6,890	0	380	11,844	1,266	0	10,868	15,285	1,615	2,127
Crittenden	37,723	29,139	1,738	0	0	0	4,405	6	3,060	7,141	10,765	2,024
Cross	69,404	54,413	758	2,221	2,477	1,814	4,871	1,954	8,055	22,755	5,812	3,696
Desha	18,616	18,447	0	186	0	5	392	8	659	1,818	14,069	1,310
Drew	8,866	10,267	0	0	0	0	1,794	5	0	1,290	6,870	308
Greene	68,721	55,281	2,269	685	0	1,345	20,163	8,590	1,966	897	10,948	8,417
Independence	9,071	8,904	650	325	325	1,521	760	0	1,521	1,521	2,281	0
Jackson	93,444	84,101	15,496	748	954	1,653	3,040	13,194	8,796	8,278	18,738	13,205
Jefferson	48,426	54,861	0	2,301	0	0	2,813	8,242	15,470	25,642	33	360
Lawrence	102,192	75,582	0	8,652	1,688	0	5,838	24	13,263	7,171	34,387	4,559
Lee	11,527	12,749	323	0	0	0	6,955	1,199	0	3,373	0	899
Lincoln	17,129	20,060	0	0	0	0	6,070	0	7,731	5,457	0	802
Lonoke	75,811	84,168	7,782	1,342	0	1,037	379	0	2,573	35,842	26,098	9,115
Mississippi	56,771	43,194	1,465	0	0	0	5,755	492	13,660	18,994	2,828	0
Monroe	39,304	40,834	0	632	0	7,167	7,300	0	3,061	13,941	5,570	3,163
Phillips	15,613	19,955	271	0	271	0	11,296	4,351	0	3,765	0	0
Poinsett	95,617	81,464	5,082	3,557	3,767	13,792	6,507	13,009	8,120	17,768	3,266	6,597
Prairie	52,027	50,771	871	213	720	2,105	5,408	1,315	9,385	20,111	8,053	2,590
Pulaski	3,351	5,219	261	0	261	0	0	0	0	2,966	0	1,732
Randolph	37,409	28,629	1,719	5,221	244	0	6,575	0	5,108	4,064	5,091	608
St. Francis	30,244	26,630	257	257	0	647	2,023	801	5,247	11,026	5,254	1,117
White	4,756	6,086	0	0	0	0	734	0	1,928	3,424	0	0
Woodruff	48,912	46,662	691	166	0	4,660	4,874	1,053	9,397	24,452	0	1,369
Others[c]	19,896	24,306	201	0	0	591	0	3,512	331	4,633	12,053	2,985
Unaccounted[d]	1,586	1,505										1,505
2022 Total		1,084,000	49,146	29,702	11,088	53,560	117,623	59,516	158,421	322,737	193,247	88,959
2022 Percent		100.00	4.53	2.74	1.02	4.94	10.85	5.49	14.61	29.77	17.83	8.21
2021 Total	1,194,000		54,400	41,761	11,567	41,978	57,313	74,693	286,902	229,071	267,792	128,525
2021 Percent	100.00		4.56	3.50	0.97	3.52	4.80	6.26	24.03	19.19	22.43	10.76

[a] Harvested acreage. Source: USDA-NASS, 2023a.

[b] Other varieties: ARoma 17, ARoma 22, CL151, CLL15, CLL17, CLM04, Jazzman-2, Jewel, Lynx, ProGold1, ProGold2, PVL03, RTv7231 MA, RT 7301, RT 7331 MA, RT 7401, RT 7501, and RT 7801.

[c] Other counties: Clark, Conway, Faulkner, Franklin, Hot Springs, Johnson, Lafayette, Little River, Logan, Miller, Perry, Pope, and Yell.

[d] Unaccounted for acres is the total difference between USDA-NASS harvested acreage estimate and estimates obtained from each county's Farm Service Agency.

Table 2. Acreage, grain yield, and production of rice in the United States from 2020 to 2022.[a]

State	Area Planted			Area Harvested			Yield			Production		
	2020	2021	2022	2020	2021	2022	2020	2021	2022	2020	2021	2022
	(1,000 ac)			(1,000 ac)			(lb/ac)			(1,000 cwt[b])		
AR	1,461	1,211	1,106	1,441	1,193	1,084	7,500	7,630	7,410	108,107	91,063	80,340
CA	517	407	256	514	405	254	8,720	9,050	8,760	44,810	36,653	22,251
LA	480	420	425	473	413	415	6,820	6,870	6,660	32,237	28,380	27,649
MS	166	105	85	165	99	84	7,420	7,540	7,370	12,241	7,465	6,191
MO	228	199	155	214	194	149	7,250	8,040	7,940	15,522	15,599	11,832
TX	184	190	195	179	181	186	8,150	6,860	6,510	14,597	12,421	12,105
US	3,036	2,532	2,222	2,986	2,485	2,172	7,619	7,709	7,383	227,514	191,581	160,368

[a] Source: USDA-NASS, 2023a.
[b] cwt = hundredweight.

Table 3. Acreage distribution of selected cultural practices for Arkansas rice production from 2020 to 2022.[a]

Cultural Practice	2020		2021		2022	
	Acreage	% of Total	Acreage	% of Total	Acreage	% of Total
Arkansas Rice Acreage	1,441,000	100.00	1,194,000	100.00	1,084,000	100.00
Soil Texture						
Clay	368,019	25.5	268,075	22.5	204,721	18.9
Clay Loam	300,045	20.8	220,061	18.4	208,746	19.3
Silt Loam	730,925	50.7	650,536	54.5	617,210	56.9
Sandy Loam	36,171	2.5	43,517	3.6	48,746	4.5
Sand	5,840	0.4	11,810	1.0	4,578	0.4
Tillage Practices						
Conventional	767,392	53.3	674,053	56.5	545,565	50.3
Stale Seedbed	543,562	37.7	424,978	35.6	425,376	39.2
No-Till	219,588	9.0	177,783	8.0	136,278	10.4
Crop Rotations						
Soybean	973,442	67.6	793,231	66.4	725,512	66.9
Rice	344,091	23.9	260,971	21.9	214,026	19.7
Cotton	2,755	0.2	1,591	0.1	5,705	0.5
Corn	55,566	3.9	68,557	5.7	71,449	6.6
Grain Sorghum	1,534	0.1	3,262	0.3	1,362	0.1
Wheat	2,344	0.2	3,093	0.3	1,391	0.1
Fallow	61,267	4.3	63,295	5.3	50,909	4.7
Other	0	0.0	0	0.0	13,643	1.3
Seeding Methods						
Drill Seeded	1,221,412	84.8	1,016,217	85.1	947,722	87.4
Broadcast Seeded	167,432	11.6	138,767	11.6	95,891	8.8
Water Seeded	52,156	3.6	39,016	3.3	40,387	3.7
Irrigation Water Sources						
Groundwater	1,114,374	77.3	921,097	77.1	852,733	78.7
Stream, Rivers, etc.	142,738	9.9	122,157	10.2	91,759	8.5
Reservoirs	183,887	12.8	150,747	12.6	139,508	12.9
Irrigation Methods						
Flood, Levees	712,463	49.4	519,261	43.5	533,558	49.2
Flood, Multiple Inlet	447,895	31.1	391,693	32.8	313,590	28.9
Intermittent (AWD)	35,873	2.5	41,668	3.5	41,350	3.8
Furrow	244,198	16.9	241,379	20.2	195,501	18.0
Sprinkler	571	0.0	0	0.0	0	0.0
Other	0	0.0	0	0.0	0	0.0
Stubble Management						
Burned	479,299	33.3	447,282	37.5	534,972	49.4
Tilled	530,180	36.8	528,258	44.2	516,699	47.7
Rolled	463,093	32.1	377,364	31.6	298,430	27.5
Winter Flooded	401,457	27.9	328,079	27.5	246,632	22.8
Land Management						
Contour levees	718,765	49.9	588,246	49.3	574,233	53.0
Precision-level	536,209	37.2	461,713	38.7	403,266	37.2
Zero-grade	192,149	13.3	144,040	12.1	106,501	9.8
Precision Agriculture						
Yield Monitors	1,141,788	79.2	971,576	81.4	887,218	81.8
Grid Sampling	520,921	36.1	489,135	41.0	351,429	32.4
Variable-rate Fertilizer	361,202	25.1	254,690	21.3	188,631	17.4
Use Pipe Planner, Phaucet	516,898	35.9	400,686	33.6	336,484	31.0
Use urea stabilizer (NBPT)	1,289,661	89.5	1,101,177	92.2	961,794	88.7
N-STaR	103,944	7.2	101,868	8.5	55,538	5.1
Use GreenSeeker handheld	40,183	2.8	42,480	3.6	36,827	3.4
Use Cover Crops	21,362	1.5	35,781	3.0	61,664	5.7
Use Sodium Chlorate	417,021	28.9	378,421	31.7	404,777	37.3
Pest Management						
Insecticide Seed Treatment	1,153,642	80.1	997,633	83.6	886,468	81.8
Fungicide (foliar app.)	868,717	60.3	719,455	60.3	634,559	58.5
Insecticide (foliar app.)	574,373	39.9	544,079	45.6	482,420	44.5

[a] Data generated from surveys of county agriculture extension agents.

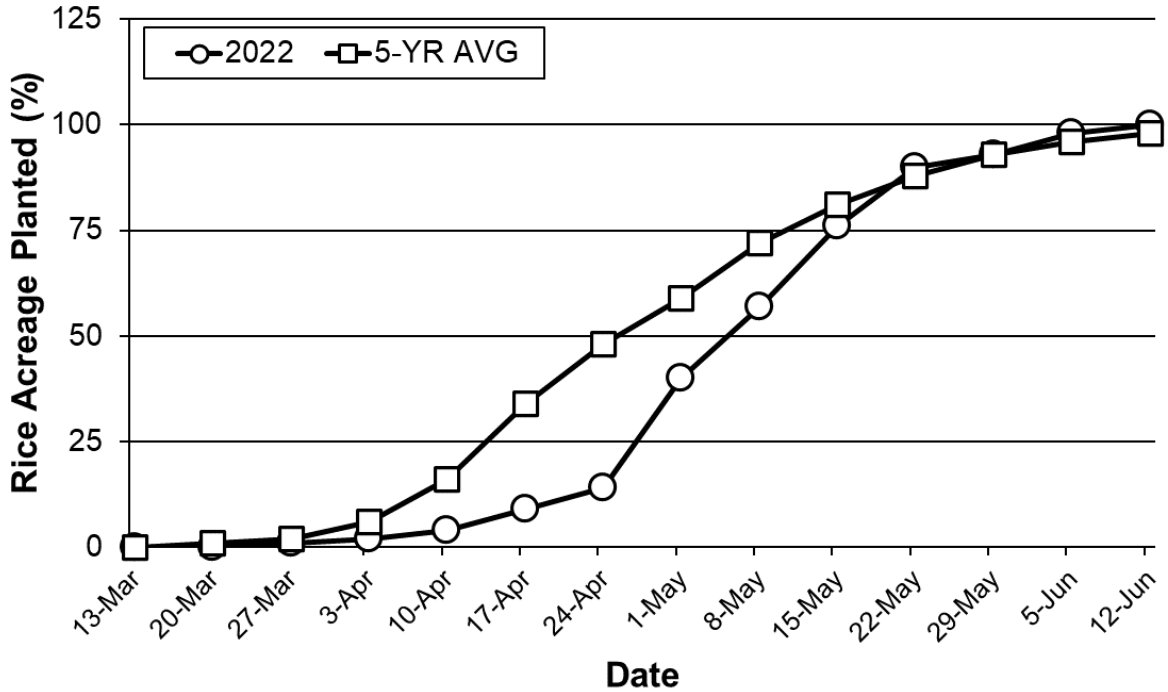

Fig. 1. Arkansas rice planting progress during 2022 compared to the five-year state average (USDA-NASS, 2023b).

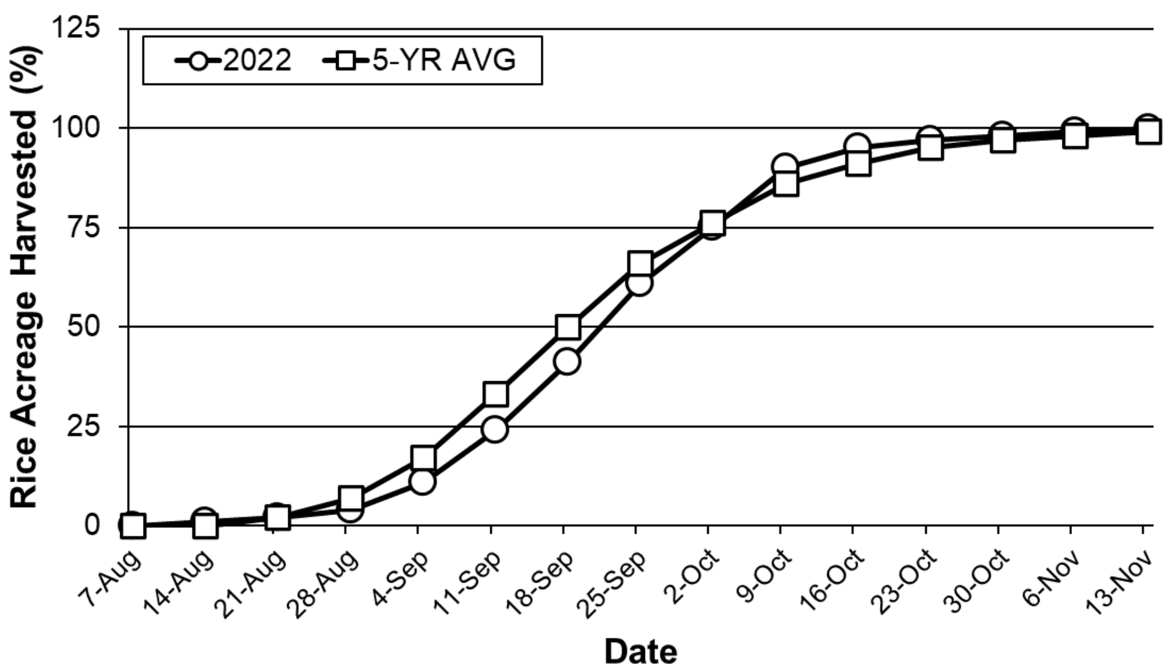

Fig. 2. Arkansas rice harvest progress during 2022 compared to the five-year state average (USDA-NASS, 2023b).

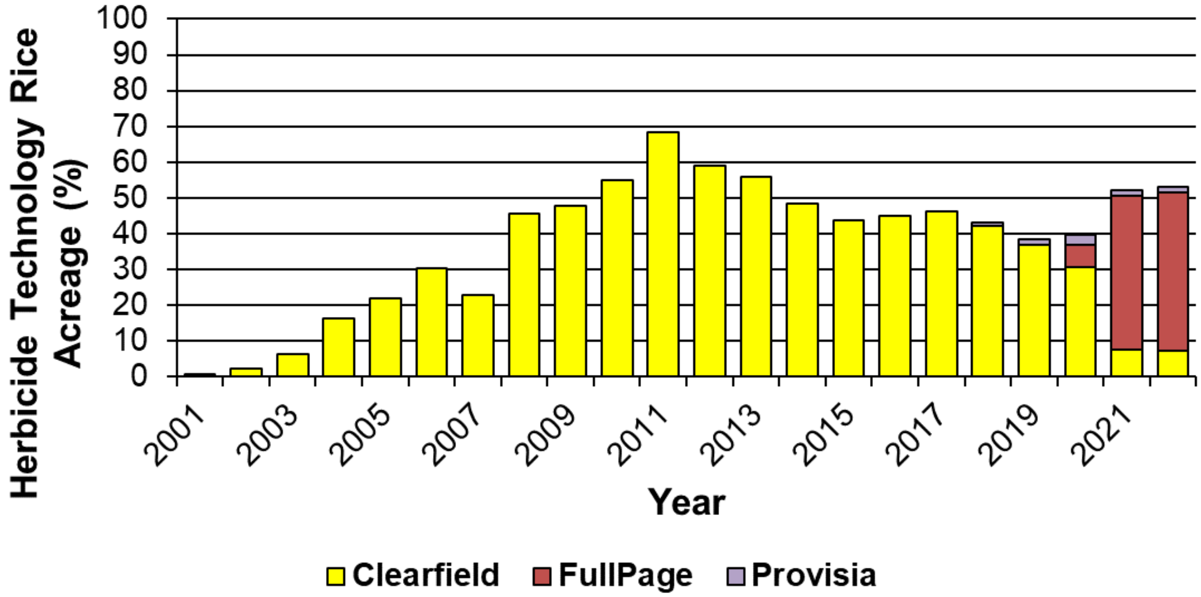

Fig. 3. Percentage of rice planted in Arkansas with herbicide technology including Clearfield, FullPage, and Provisia rice cultivars between 2001 and 2022.

2022 Rice Research Verification Program

R.S. Mazzanti,[1] J.T. Hardke,[1] and K.B. Watkins[2]

Abstract

The 2022 Rice Research Verification Program (RRVP) was conducted on 9 commercial rice fields across Arkansas. Counties participating in the program included Arkansas, Crittenden, Drew, Jefferson, Lonoke, Mississippi, Monroe, Phillips, St. Francis for a total of 421 acres. Grain yield in the 2022 RRVP averaged 176 bu./ac, ranging from 145 to 218 bu./ac. The 2022 RRVP average yield was 11 bu./ac greater than the estimated Arkansas state average of 165 bu./ac. The highest-yielding field was Mississippi County with a yield of 218 bu./ac. The lowest-yielding field was Arkansas tied with St. Francis County and produced 145 bu./ac. Milling quality in the RRVP averaged 50/67 (% head rice/% total milled rice). The Mississippi Co. field had the greatest returns to operating costs of $747.46/ac while the St. Francis Co. field had the lowest returns to operating costs of $199.60/ac.

Introduction

In 1983, the University of Arkansas System Division of Agriculture's Cooperative Extension Service established an interdisciplinary rice educational program that stresses management intensity and integrated pest management to maximize returns. The purpose of the Rice Research Verification Program (RRVP) was to verify the profitability of Cooperative Extension Service (CES) recommendations in fields with less than optimum yields or returns.

The goals of the RRVP are to: 1) educate producers on the benefits of utilizing CES recommendations to improve yields and/or net returns, 2) conduct on-farm field trials to verify research-based recommendations, 3) aid researchers in identifying areas of production that require further study, 4) improve or refine existing recommendations which contribute to more profitable production, and 5) incorporate data from RRVP into CES educational programs at the county and state level. Since 1983, the RRVP has been conducted on 501 commercial rice fields in 33 rice-producing counties in Arkansas. Since the program's inception 37 years ago, RRVP yields have averaged 18 bu./ac better than the state average. This increase in yield over the state average can mainly be attributed to intensive cultural management and integrated pest management.

Procedures

The RRVP fields and cooperators are selected prior to the beginning of the growing season. Cooperators agree to pay production expenses, provide expense data, and implement CES recommendations in a timely manner from planting to harvest. A designated county agent from each county assists the RRVP coordinator in collecting data, scouting the field, and maintaining regular contact with the producer. Weekly visits by the coordinator and county agents are made to monitor the growth and development of the crop, determine what cultural practices need to be implemented and monitor type and level of weed, disease and insect infestation for possible pesticide applications.

An advisory committee, consisting of CES specialists and university researchers with rice responsibility, assists in decision-making, development of recommendations, and program direction. Field inspections by committee members are utilized to assist in fine-tuning recommendations.

Counties participating in the program during 2022 included: Arkansas, Crittenden, Drew, Jefferson, Lonoke, Mississippi, Monroe, Phillips, and St. Francis. The 9 rice fields totaled 421 acres enrolled in the program. Four different cultivars were seeded: RT 7521 FP (3 fields); RT 7321 FP (1 field); DG263L (4 fields); and RT 7401 (1 field). University of Arkansas System Division of Agriculture CES recommendations were used to manage the RRVP fields. Agronomic and pest management decisions were based on field history, soil test results, rice cultivar, and data collected from individual fields during the growing season. An integrated pest management philosophy was utilized based on CES recommendations. Data collected included components such as stand density, weed populations, disease infestation levels, insect populations, rainfall, irrigation amounts, dates for specific growth stages, mid-season nitrogen levels, grain yield, milling yield, and grain quality.

Results and Discussion

Yield

The average RRVP yield was 176 bu./ac with a range of 145 to 218 bu./ac (Table 1). All grain yields of RRVP fields are reported in dry bushels corrected to 12% moisture. A bushel of rice is 45 lb. The RRVP average was 11 bu./ac more than the estimated state average yield of 165 bu./ac. Similar yield differences have been observed since the program began and can be attributed in part to intensive management practices and utilization of CES recommendations. The Mississippi County field, seeded with RT 7521 FP, was the highest-yielding RRVP field at 218 bu./ac. Six fields enrolled in the program met or exceeded the 165 bu./ac state average yield. Arkansas and St. Francis County were late-planted and both resulted in the lowest yield of 145 bu./ac.

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Milling data was recorded on all the RRVP fields. The average milling yield for the 9 fields was 50/67 (% head rice/% total milled rice). The highest milling yield was 58/69 with DG263L in St. Francis County (Table 1). The lowest milling yield was 42/71 with RT 7401 in Lonoke County. The milling yield of 55/70 is considered the standard used by the rice milling industry.

Planting and Emergence

Planting began with Drew and Jefferson counties on 10 April and ended with Arkansas and Monroe counties on 12 May (Table 1). Four of the verification fields were planted in April and 5 in May. An average of 44 lb of seed/ac was planted for pure-line varieties and 22 lb seed/ac for hybrids. Seeding rates were determined with the CES RICESEED program for all fields. An average of 14 days was required for emergence. Stand density averaged 11 plants/ft^2 for pure-line varieties and 9 plants/ft^2 for hybrids. The seeding rates in some fields were slightly higher than average due to soil texture and planting date. Clay soils generally require an elevated seeding rate to achieve desired plant populations.

Fertilization

The Nitrogen Soil Test for Rice (N-STaR) was utilized for 5 RRVP fields and reduced the total nitrogen (N) recommendation by an average of 15 lb N/ac when compared with the standard N recommendation. However, row rice fields call for additional N in 2 fields during the season. The recommendations prompting the N additions are described in the field reviews and the amounts are included in Table 2.

As with standard N recommendations for rice, N-STaR N recommendations consider a combination of factors including soil texture, previous crop, and cultivar requirements (Tables 1 and 2). The GreenSeeker hand-held crop sensor was used at least weekly in all fields after panicle initiation through late boot stage to verify that N levels were adequate for the targeted yield potential.

Phosphorus (P), potassium (K), and zinc (Zn) fertilizers were applied based on soil test analysis recommendations (Table 2). Phosphorus was applied pre-plant to Arkansas, Crittenden, Drew, Lonoke, Mississippi and Phillips and St. Francis County fields. Potassium was applied to Arkansas, Drew, Lonoke, Mississippi, Monroe, Phillips and St. Francis County fields. Zinc was applied as a pre-plant fertilizer to the Arkansas County field while zinc seed treatment was used with all hybrid and pure-line rice cultivars at a rate of 0.5 lb Zn/cwt. The average per-acre cost of fertilizer across all fields was $227.84.

Weed Control

Clomazone (e.g., Command) herbicide was utilized as either a stand-alone, premix or tank mix application in all 9 program fields for early-season grass control (Table 3). Quinclorac (e.g., Facet) was utilized in 6 of 8 fields, again, as either a stand-alone, premix or tank mix application for both pre-emergence and early post-emergence treatments. Overlapping residuals proved to be an effective strategy utilized in all fields. A combination of both grass and broadleaf residuals was used in each field. Four fields (Arkansas, Crittenden, Mississippi and Phillips Counties) were seeded in imidazolinone (IMI) tolerant cultivars or FullPage technologies (Table 1).

Disease Control

A foliar fungicide was applied in 4 of the 9 program fields (Crittenden, Drew, Monroe and Phillips Counties). These were preventive treatments applied for kernel smut and false smut diseases (Table 4). Generally, fungicide rates are determined based on cultivar, growth stage, climate, disease incidence/severity, and disease history. However, preventative treatments for kernel or false smut and rice blast require specific rates depending on the product used. Nine fields had a seed treatment containing a fungicide.

Insect Control

Five fields (Arkansas, Crittenden, Drew, Mississippi and Monroe Counties) were treated with a foliar insecticide application for rice stink bug (Table 4). All 9 fields received an insecticide seed treatment.

Irrigation

Well water was used exclusively for irrigation in all 9 of the fields in the 2022 RRVP. Two fields (Drew and Monroe Counties) were grown under furrow irrigated rice (FIR; row rice) management. Multiple Inlet Rice Irrigation (MIRI) was utilized in the 3 conventionally flooded fields. Typically, a 25% reduction in water use is observed when using MIRI which employs polytube irrigation and a computer program to determine the size of tubing required plus the correct number and size of holes punched into it to achieve uniform flood-up across the field. Flow meters were used in 6 fields to record water usage throughout the growing season (Table 5). In 3 fields where flow meters for various reasons could not be utilized, the average across all irrigation methods (30 inches) was used. The difference in irrigation water used was due in part to rainfall amounts which ranged from a low of 6.25 inches to a high of 16.3 inches.

Economic Analysis

This section provides information on production costs and returns for the 2022 Rice Research Verification Program (RRVP). Records of field operations on each field provided the basis for estimating production costs. The field records were compiled by the RRVP coordinators, county Extension agents, and cooperators. Production data from the 8 fields were applied to determine costs and returns above operating costs, as well as total specified costs. Operating costs and total costs per bushel indicate the commodity price needed to meet each cost type.

Operating costs are those expenditures that would generally require annual cash outlays and would be included on an annual operating loan application. Actual quantities of all operating inputs as reported by the cooperators are used in this analysis. Input prices are determined by data from the 2022 Crop Enterprise Budgets published by the Cooperative Extension Service and information provided by the cooperating producers. 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 provide unpaid labor for equipment maintenance.

Fixed 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 representative prices of new equipment. This measure differs from typical depreciation methods, as well as actual annual cash expenses for machinery.

Operating costs, fixed costs, costs per bushel, and returns above operating and total specified costs are presented in Table 6. Costs in this report do not include land costs, management, or other expenses and fees not associated with production. Operating costs ranged from \$693.28/ac for Jefferson County to \$1,042.98 for Phillips County, while operating costs per bushel ranged from \$3.51/bu. for Mississippi County to \$5.89/bu. for St. Francis County. Total costs per acre (operating plus fixed) ranged from \$766.62/ac for Jefferson County to \$1,142.61/ac for Phillips County, and total costs per bushel ranged from \$3.85/bu. for Mississippi County to \$6.64/bu. for St. Francis County. Returns above operating costs ranged from \$199.60/ac for St. Francis County to \$747.46/ac for Mississippi County and returns above total costs ranged from \$80.12/ac for Arkansas County to \$673.57/ac for Mississippi County.

A summary of yield, rice price, revenues, and expenses by expense type for each RRVP field is presented in Table 7. The average rice yield for the 2022 RRVP was 176 bu./ac but ranged from 145 bu./ac for Arkansas County to 218 bu./ac for Mississippi County. An Arkansas average long-grain cash price of \$7.23/bu. was estimated using USDA, National Agricultural Statistics Service (NASS) U.S. long-grain price data for the months of August through October. The RRVP had all fields planted to long-grain rice. A premium or discount was given to each field based on the milling yield observed for each field, a standard milling yield of 55/70 for long-grain rice, and 2022 loan values for whole kernels (\$11.13/cwt; \$5.01/bu.) and broken kernels (\$6.47/cwt; \$2.91/bu.). Estimated long-grain prices adjusted for milling yield varied from \$6.85/bu. in Drew County to \$7.26/bu. in St. Francis County (Table 7).

The average operating expense for the 9 RRVP fields was \$/acre (Table 7). Fertilizer and nutrient expenses accounted for the largest share of operating expenses on average (26.8%) followed by chemicals (17.1%), seed (14.0%), and post-harvest expenses (12.5%). Although seed's share of operating expenses was 14.0% across the 9 fields, its average cost and share of operating expenses varied depending on whether a proprietary non-herbicide tolerant pure-line cultivar was used (\$72.92/ac; 9.26% of operating expenses), a non-herbicide tolerant hybrid was used (\$136.19/ac; 15.21% of operating expenses), or a herbicide-tolerant hybrid was used (\$160.68/ac; 17.87% of operating expenses).

The average return above operating expenses for the 9 fields was \$387.96/ac and ranged from \$199.60/ac for St. Francis County to \$747.46/ac for Mississippi County. The average return above total specified expenses for the 9 fields was \$293.10/ac and ranged from \$80.12/ac for Arkansas County to \$673.57/ac for Mississippi County. Table 8 provides select variable input costs for each field and includes a further breakdown of chemical costs into herbicides, insecticides, and fungicides. Table 8 also lists the specific rice cultivars grown on each RRVP field.

Field Summaries

Arkansas County

The Arkansas County was located just North of Reydell (Bayou Meto) on Hebert silt loam soil. Conventional tillage practices were used for spring preparation. The field consisted of 38 acres and the previous crop grown was soybean. The cultivar chosen was RT 7321 FP treated with the company's standard seed treatment. The field was drill-seeded at 22 lb/ac and planted 12 May. Emergence was observed on 28 May with a stand count of 6.4 plants/ft^2. A field cultivator and land plane were used prior to planting. According to the soil test a 0-0-60 (lb/ac N-P_2O_5-K_2O) was applied in the spring. Preface and Prowl herbicides were applied at planting as pre-emergence herbicides on 24 May. Facet, Prowl, and Preface were applied as post-emergence herbicides on 4 June. Regiment, Command, and League herbicides were applied 11 June for weed escapes. N-STaR (Nitrogen Soil Test for Rice) samples were taken on the field. Nitrogen (N) in the form of urea plus an approved NBPT was applied at 275 lb/ac on 14 June followed by 70 lb/ac on 26 July. Surface water was adequately maintained with use of a re-lift pump. Using Trimble GreenSeeker technology, the N response levels remained adequate throughout the growing season. Rice stink bug numbers reached treatment level and Endigo insecticide was applied 10 August. The field was harvested on 26 September yielding 145 bu./ac and a milling yield of 49/72. The disappointing yield was thought to be from late planting and high heat during pollination. The average harvest moisture was 17.2%. Total irrigation was 28 ac-in., and total rainfall was 7.9 inches.

Crittenden County

The no-till Crittenden County field was located just north of Crawfordsville on a Sharkey silty clay soil. The field consisted of 49 acres and the previous crop grown was soybean. The cultivar chosen was RT 7321 FP treated with the company's standard seed treatment. The field was drill-seeded at 22 lb/ac and planted 29 April. Glyphosate was applied as a burndown herbicide on 3 May. Preface, Command, and Sharpen herbicides were applied at planting on 9 May as pre-emergence herbicides. Emergence was observed on 9 May with a stand count of 7 plants/ft^2. No tillage practices were used for spring field preparation. According to the soil test a fertilizer blend of 0-46-0 lb/ac (N-P_2O_5-K_2O) was applied in the spring. Regiment, Command, and Postscript were applied as post-emergence herbicides on 1 June. N-STaR was utilized on the field. Nitrogen in the form of urea plus an approved NBPT was applied at 260 lb/ac on 23 May, followed by 70 lb/ac on 7 June. Using Trimble GreenSeeker, the N response levels remained adequate throughout the season. An adequate flood was maintained throughout the growing season. Quilt Excel was applied 20 June for smut prevention due to history. Rice stink bugs numbers reached treatment levels and lambda cyhalothrin was applied 5 July. The field was harvested on 11 September yielding 201 bu./ac and a milling yield of 52/69. The average harvest moisture was 16%. Total irrigation was 30 ac-in., and rainfall totaled 13 inches.

Drew County

The Drew County furrow-irrigated rice (FIR) field was located just west of Tiller on a Portland clay soil. The field consisted of

41 acres and the previous crop grown was soybean. The cultivar chosen was DG263L treated with the company's standard seed treatment. The field was drill-seeded at 45 lb/ac and planted 10 April. Emergence was observed on 7 May with a stand count of 12 plants/ft^2. In the spring, no tillage practices were used. According to the soil test a 0-46-0 lb/ac (N-P_2O_5-K_2O) fertilizer blend was applied in the spring. Glyphosate, Command, and Sharpen herbicides were applied at planting on 10 April. Rebel EX was applied as a post-emergence herbicide on 16 May. Regiment herbicide was applied 6 June. N-STaR samples were taken on the field. Nitrogen in the form of urea plus an approved NBPT was applied at 165 lb/ac on 20 May followed by 165 lb/ac on 6 June, followed by 100 lb/ac on 22 June. Using Trimble GreenSeeker, the N response levels remained adequate throughout the season. Intermittent flushing was utilized for irrigation. Propiconazole fungicide was sprayed as smut prevention 25 June. Sheath blight disease exceeded threshold levels and Quilt Xcel fungicide was applied 10 July. Rice stink bugs reached threshold levels and lambda-cyhalothrin was applied 26 July. Rice stink bug numbers continued to increase and Endigo insecticide was applied 11 August. The field was harvested on 1 September yielding 165 bu./ac and a milling yield of 48/62. The average harvest moisture was 17%. Total irrigation was 8.57 ac-in., and total rainfall was 16.3 inches.

Jefferson County

The 68-acre Jefferson County field was located just north of Reydell on a silty clay loam soil. No tillage practices were chosen for the field. No pre-plant fertilizer was necessary according to the soil sample analysis. The field was drill-seeded 10 April with DG263L at 40 lb/ac. The seed was treated with the company's standard seed treatment. Rice emergence was observed on 29 April at 13 plants ft^2. Command, League, and Roundup were used as pre-emergence and burndown herbicides on 10 April. Propanil, Facet, and RiceOne were applied as post-emergence herbicides on 7 May. Levee construction was delayed resulting in an additional herbicide application. Propanil and Permit Plus herbicides were applied 6 June. Using the N-STaR recommendation N fertilizer in the form of urea plus NBPT was applied at 260 lb/ac on 8 June. The mid-season N application was applied 1 July at 100 lb/ac. GreenSeeker technology was utilized during midseason growth stages to monitor the crop's N level. No treatments were necessary for disease or insects. The field was harvested 14 September. The yield was 165 bu./ac. The milling yield was 50/62 and average harvest moisture was 13%. Total irrigation use was 30 ac-in., and rainfall totaled 14.1 inches.

Lonoke County

The 72-acre contour field was located west of Parker's Corner on a Dewitt silt loam soil. Conventional tillage practices were utilized and a pre-plant fertilizer blend was applied at 0-40-60-5 lb/acre (N-P_2O_5-K_2O-Zn) according to soil test recommendations. Glyphosate, Command, and Sharpen were applied as burndown and pre-emergence herbicides 10 May. The cultivar RT 7401 treated with the company's standard seed treatment was drill-seeded at 22 lb/ac on 10 May. Stand emergence was observed on 16 May with 11.1 plants/ft^2. Facet and Permit Plus were applied as post-emergence herbicides on 17 June. Nitrogen fertilizer in the form of urea plus NBPT was applied 18 June. The urea was applied at 260 lb/ac according to the N-STaR fertilizer recommendation. Multiple-inlet rice irrigation (MIRI) was utilized to achieve a more efficient permanent flood. GreenSeeker technology was utilized during midseason growth stages to monitor the crop's N level. The late-boot N fertilizer application was made on 27 July at 70 lb/ac. The field required no treatments for disease or insects. The field was harvested on 28 September yielding 177 bu./ac and a milling yield of 42/71. Total irrigation usage use was 30 ac-in., and total rainfall was 6.25 inches.

Mississippi County

The precision-graded Mississippi County field was located just west of Burdette on a Sharkey-Steel complex soil. The field was no-till and based on soil test analysis a pre-plant fertilizer blend was applied at 0-50-60 lb/ac (N-P_20_5-K_20). On 30 April, RT 7321 FP treated with the company's standard seed treatment was drill-seeded at 23 lb/ac. Command and Roundup were applied at planting as pre-emergence and burndown herbicides. Stand emergence was observed on 11 May with 8.3 plants/ft^2. Preface and Facet herbicides were applied on 20 May. Nitrogen fertilizer in the form of urea plus NBPT was applied at 270 lb/ac on 20 May, according to the N-STaR recommendation. The late-boot urea application of 80 lb/ac was made on 11 July. Stink bugs reached treatment level and the field was sprayed with Endigo insecticide on 16 August. The field was harvested 23 September yielding 218 bu./ac with a milling yield of 48/65. The harvest moisture was 13%. Total irrigation use was 30 ac-in., and rainfall totaled 12.0 inches.

Monroe County

The 44-acre furrow irrigated rice (FIR) field was located east Clarendon. The soil classification is a Foley-Bonn complex soil. Spring conventional tillage practices were used for field preparation and based on soil analysis a 0-0-50 lb/ac (N-P_2O_5-K_2O) fertilizer blend was applied 4 April. The cultivar DG263L treated with the company's standard seed treatment was drill-seeded at 45 lb/ac on 12 April. Command, Sharpen, and Glyphosate were applied at planting as pre-emergence and post-emergence herbicides. Emergence was observed on 28 April with 10 plants/ft^2. Facet L and Permit Plus herbicides were applied 17 May. N-STaR samples were taken on the field and N fertilizer as urea was applied at 100 lb/ac on 21 June followed by 100 lb/ac on 30 June. Another 100 lb/ac was applied on 12 July followed by 100 lb/ac on 22 July. GreenSeeker technology was utilized during growth stages to monitor the crop's N level. Barnyard grass escapes were spotty and Clincher herbicide was spot sprayed. Propiconazole fungicide was sprayed 11 July due to a history of smuts. Stink bugs reached treatment level and lambda-cyhalothrin was applied on 9 August. The field was harvested 29 August yielding 170 bu./ac. The milling yield was 55/63 and the average harvest moisture was 18%. Total irrigation for the season was 26 ac-in., and total rainfall was 3.95 inches.

Phillips County

The precision-graded field was located just west of Helena on a Newellton silty clay soil. Spring conventional tillage practices were used for field preparation and based on soil analysis a 0-40-60 lb/ac (N-P_2O_5-K_2O) fertilizer blend was applied 4 April. On 1 May, RT 7521 FP treated with the company's standard seed treatment was drill-seeded at 22 lb/ac. Command, Facet L, and Roundup were applied at planting as pre-emergence and burndown herbicides. Stand emergence was observed on 14 May with 12 plants/ft^2. Newpath, SuperWham, and Facet L herbicides were applied on 19 May. Regiment and Newpath herbicides were applied 30 May. Nitrogen fertilizer in the form of urea plus NBPT was applied at 275 lb/ac on 2 June, according to the N-STaR recommendation. The late-boot urea application of 70 lb/ac was applied on 22 July. Quilt Xcel was applied 10 July as a smut preventative. The field was harvested 1 September yielding 200 bu./ac with a milling yield of 49/66. The harvest moisture was 17%. Total irrigation use was 30 ac-in., and rainfall totaled 12.5 inches.

St. Francis County

The 42-acre contour field was located south of Pine Tree on a Calloway silt loam soil. Conventional tillage practices were utilized, and a pre-plant fertilizer blend was applied at 0-60-90 lb/ac (N-P_2O_5-K_2O) according to the soil test. Glyphosate and 2,4-D amine were used as burndown herbicides in the spring. The cultivar DG263L treated with the company's standard seed treatment was drill-seeded at 42 lb/ac on 1 May. Command was applied as a pre-emergence herbicide 3 May. Stand emergence was observed 12 May with 10 plants/ft^2. Facet L and Permit Plus were applied as post-emergence herbicides on 12 May. Sharpen herbicide was applied on 16 May. Nitrogen fertilizer in the form of urea plus NBPT was applied 2 June at 200 lb/ac according to the N-STaR recommendation. MIRI was utilized to achieve a more efficient permanent flood since the levees were numerous. GreenSeeker technology was utilized during midseason growth stages to monitor the crop's N level. The midseason N fertilizer application was made on 13 July at 100 lb/ac. The field required no treatments for disease or insects. The field was harvested on 29 September yielding 145 bu./ac and a milling yield of 58/69. The harvest moisture averaged 12%. Total irrigation usage use was 30 ac-in., and total rainfall was 8.1 inches.

Practical Applications

Data collected from the 2022 RRVP reflects the continued general trend of improved rice yields and returns. Analysis of this data showed that the average yield was significantly higher in the RRVP compared to the state average and the cost of production was equal to or less than the Cooperative Extension Service-estimated rice production costs.

Acknowledgments

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Table 1. Agronomic information for fields enrolled in the 2022 Rice Research Verification Program.

Field location by County	Cultivar	Field size	Previous crop	Seeding rate	Stand density	Planting date	Emergence date	Harvest date	Yield	Milling yield [a]	Harvest Moisture
		(ac)		(lb/ac)	(plants/ft^2)				(bu./ac)	(%HR/%TR)	(%)
Arkansas	RT 7321 FP	38	Soybean	22	6	12-May	28-May	26-Sept	145	49/72	17%
Crittenden	RT 7321 FP	40	Soybean	22	7	29-April	9-May	11-Sept	201	52/69	16%
Drew	DG 263L	41	Soybean	45	12	10-April	7-May	1-Sept	165	48/62	17%
Jefferson	DG 263L	68	Fallow	40	13	10-April	29-April	14-Sept	165	50/62	13%
Lonoke	RT 7401	72	Soybean	22	11	10-May	16-May	28-Sept	177	42/71	12%
Mississippi	RT 7521 FP	36	Soybean	23	8	30-April	11-May	23-Sept	218	48/65	13%
Monroe	DG 263L	44	Soybean	45	10	12-May	28-May	29-Aug	170	55/63	18%
Phillips	RT 7321 FP	40	Soybean	22	12	1-May	14-May	29-Sept	200	49/66	17%
St. Francis	DG 263L	42	Soybean	45	10	1-May	9-May	29-Sept	145	58/69	12%
Average		**47**	------	**32[b]**	**10[c]**	**12-May**	**17-May**	**18-Sept**	**176**	**50/67**	**15%**

[a] Milling yield numbers: First number = % Head rice (whole white grains)/Second number = % Total white rice (whole grains + broken grains).
[b] Seeding rates averaged 78 lb/ac for conventional cultivars and 24 lb/ac for hybrid cultivars.
[c] Stand density averaged 18 plants/ft^2 for conventional cultivars and 7 plants/ft^2 for hybrid cultivars.

Table 2. Soil test results, fertilization, and soil classification for fields enrolled in the 2022 Rice Research Verification Program.

					Applied Fertilizer			
		Soil Test						
Field Location by County	pH	P	K	Zn	Mixed Fertilizer[a] N-P-K-Zn[b]	N-Star Urea (46%N) rates and timing [c, d]	Total N rate	Soil Classification
	---------------(lb/ac)---------------				----------------------(lb/ac)----------------------		(lb N/ac)	
Arkansas	6.5	56	260	6.2	0-60-60-10	275-70	159	Hebert Silt Loam
Crittenden	6.9	50	567	5.4	0-50-0-0	260-70	152	Sharkey-Silty Clay
Drew	6.3	86	469	7.8	0-40-0-0	165-165-100[e]	198	Portland Clay
Jefferson	7.1	59	683	9.3	0-0-0-0	260-100	165	Portland Clay and Rilla Silt Loam
Lonoke	6.1	30	209	3.3	0-40-60-0	260-70	152	Dewitt and Stuttgart Silt Loam
Mississippi	6.9	71	508	9.5	0-50-60-0	270-80	161	Sharkey-Steel Complex
Monroe	7.1	64	423	9.5	0-40-0-0	100-100-100-100[e]	184	Foley-Calhoun-Bonn Complex
Phillips	7.1	35	198	6.8	0-40-60-0	275-70	160	Loring-Memphis-Collins
St. Francis	6.6	18	115	4.6	0-60-90-0	200-100	138	Calhoun-Henry Silt Loam

[a] Column represents regular pre-plant applications.
[b] N = nitrogen, P = phosphorus, K = potassium, Zn = zinc.
[c] Timing: preflood – midseason – boot. Each field was fertilized according to its N-STaR recommendation.
[d] N-Star preflood N recommendation in all fields was treated with an approved N-(n-butyl) thiophosphoric triamide (NBPT) product to minimize N loss due to ammonia volatilization.
[e] Row rice fields received additional seasonal N exceeding the N-Star recommendation by 46 lb.

Table 3. Herbicide rates and timings for fields enrolled in the 2022 Rice Research Verification Program.

Field Location by County	Pre-emergence Herbicide Applications	Post-emergence Herbicide Applications
	(Product trade name and rate/ac)[a]	
Arkansas	Preface (6 oz) + Prowl (2.1 pt) + Facet (32 oz)	Regiment (0.6 oz) + Command (12.8 oz) + League (6.4 oz) + Triple Play (1 pt)
Crittenden	Glyphosate (32 oz) fb Preface (6 oz) + Command (10 oz)	Regiment (0.5 oz) + Command (10 oz) + Postscript (5 oz) + Triple Play (1 pt)
Drew	Command (20 oz) + Glysophate (32 oz) + Sharpen (2 oz)	Rebel EX (20 oz) fb Regiment (0.6 oz) + Triple Play (1 pt)
Jefferson	Command (16 oz) + Roundup Power Max (20 oz) + League (6.4 oz)	Propanil (3 qt) + Facet L (22 oz) + Rice One (1 qt) fb Propanil (3 qt) + Permit Plus (0.75 oz) + COC (1 pt)
Lonoke	Command (20 oz) + Glyphosate (32 oz) + Sharpen (2 oz)	Facet l (32 oz) + Permit Plus (0.75 oz) + COC (1 pt)
Mississippi	Command (16 oz) + Roundup power max (28 oz)	Preface (4 oz) + Facet L (32 oz) + COC (1 pt)
Monroe	Command (16 oz) + Glyphosate (32 oz) + Sharpen (2 oz)	Facet L (32 oz) + Permit Plus (0.75 oz) fb Clincher (20 oz) + COC (1 pt)
Phillips	Command (16 oz) + (Roundup Power Max (28 oz) + Facet L (32 oz)	Newpath (6 oz) + SuperWham (4 qts) + Facet L (16 oz) fb Regiment (0.5 oz) + Triple Play (1 pt)
St. Francis	Glyphosate (32 oz) + 2,4-D amine (16 oz) fb Command (16 oz)	Permit Plus (0.75 oz) + Facet L (32 oz) + COC (1 pt) fb Rice shot (4 qt) + Sharpen (1 oz) + MSO (1 pt)

[a] fb = followed by and is used to separate herbicide application events; COC = crop oil concentrate; MSO = methylated seed oil.

Table 4. Seed treatments, foliar fungicide, and insecticide applications made in the 2022 Rice Research Verification Program.

	Seed treatments	Foliar fungicide and insecticide applications			
Field Location by county	Fungicide and/or insecticide seed treatment for control of diseases and insects of seedling rice	Fungicide applications for control of sheath blight/kernel smut/false smut	Fungicide applications for control of rice blast	Insecticide applications for control of rice water weevil	Insecticide applications for control of rice stink bug/chinch bug
	(Product trade name and rate/cwt seed)	(Product trade name and rate/ac)			
Arkansas	RTST[a]	------	------	------	Endigo (5 oz)
Crittenden	RTST	Quilt Excel (14 oz)	------	------	Lambda-Cyhalothrin (4 oz)
Drew	DGST[b]	Propiconazole (6 oz) Quilt Excel (17 oz)	------	------	Endigo (5 oz)
Jefferson	DGST	------	------	------	------
Lonoke	RTST	------	------	------	------
Mississippi	RTST	------	------	------	Lambda-Cyhalothrin (2oz) Endigo (5oz)
Monroe	RTST	Propiconazole (6 oz)	------	------	Lambda-Cyhalothrin (2 oz)
Phillips	RTST	Quilt Excel (16 oz)	------	------	------
St. Francis	DGST	------	------	------	------

[a] RTST = RiceTec Seed Treatment. This abbreviation defines those fields with seed treated by RiceTec, Inc. prior to seed purchase. RTST seed is treated with zinc compounds intended to enhance germination and early-season plant growth.

[b] DGST = Nutrien Dyna-Gro Seed Treatment. This abbreviation defines those fields with seed treated by Nutrien Ag Solutions prior to seed purchase. DGST seed is treated with zinc compounds intended to enhance germination and early-season plant growth.

Table 5. Rainfall and irrigation information for fields enrolled in the 2022 Rice Research Verification Program.

Field location by county	Rainfall	Irrigation[a]	Rainfall + Irrigation
	(in.)	(ac-in.)	(in.)
Arkansas	7.9	28	35.9
Crittenden	13.0	30*	43.0
Drew	16.3	8.57	24.87
Jefferson	14.1	30*	44.1
Lonoke	6.25	30*	36.25
Mississippi	12.0	30*	42.0
Monroe	3.95	26	29.95
Phillips	12.5	30	42.5
St. Francis	8.1	30*	38.1

[a] Not all fields were equipped with flow meters to monitor water use for irrigation. Therefore, the historical average irrigation amount in fields with flow meters was used for fields with no irrigation data. Irrigation amounts using this calculated average are followed by an asterisk (*).

Table 6. Operating costs, total costs, and returns for fields enrolled in the 2022 Rice Research Verification Program.

County	Operating Costs	Operating Costs	Returns to Operating Costs	Fixed Costs	Total Costs	Returns to Total Costs	Total Costs)
	($/ac)	($/bu.)	($/ac)	($/ac)	($/ac)	($/ac)	($/bu.)
Arkansas	829.84	5.72	208.71	128.59	958.43	80.12	6.61
Crittenden	959.46	4.77	475.27	94.20	1,053.67	381.07	5.24
Drew	759.18	4.60	371.12	70.62	829.80	300.50	5.03
Jefferson	693.28	4.20	443.93	73.34	766.62	370.60	4.65
Lonoke	895.34	5.06	341.27	111.67	1,007.01	229.60	5.69
Mississippi	764.94	3.51	747.46	73.90	838.84	673.57	3.85
Monroe	844.73	4.97	349.72	93.24	937.97	256.48	5.52
Phillips	1042.98	5.21	354.57	99.64	1,142.61	254.93	5.71
St. Francis	853.65	5.89	199.60	108.54	962.18	91.07	6.64
Average	**849.27**	**4.88**	**387.96**	**94.86**	**944.13**	**293.10**	**5.44**

Table 7. Summary of Revenue and Expenses per Acre for fields enrolled in the 2022 Rice Research Verification Program.

Item	Arkansas	Crittenden	Drew	Jefferson	Lonoke
Yield (bu.)	145	201	165	165	177
Price Received ($/bu.)	7.16	7.14	6.85	6.89	6.99
Total Crop Revenue	**1038.55**	**1434.73**	**1130.30**	**1137.22**	**1236.61**
Operating Expenses					
Seed	160.36	160.36	75.00	66.67	136.19
Fertilizers and Nutrients	203.56	202.55	238.49	164.75	253.94
Chemicals	181.07	154.70	160.28	166.85	91.31
Custom Applications	54.00	74.80	76.00	52.80	52.30
Diesel Fuel	25.23	17.74	17.93	16.75	27.48
Repairs and Maintenance	27.50	25.11	18.31	20.87	24.79
Irrigation Energy Costs	25.42	137.84	15.05	45.66	137.84
Labor, Field Activities	48.35	46.13	44.18	45.73	46.81
Other Inputs and Fees, Pre-harvest	16.86	18.94	14.36	13.62	17.86
Post-harvest Expenses	87.51	121.30	99.58	99.58	106.82
Total Operating Expenses	**829.84**	**959.46**	**759.18**	**693.28**	**895.34**
Returns to Operating Expenses	**208.71**	**475.27**	**371.12**	**443.93**	**341.27**
Capital Recovery and Fixed Costs	128.59	94.20	70.62	73.34	111.67
Total Specified Expenses[a]	**958.43**	**1053.67**	**829.80**	**766.62**	**1007.01**
Returns to Specified Expenses	**80.12**	**381.07**	**300.50**	**370.60**	**229.60**
Operating Expenses/bu.	5.72	4.77	4.60	4.20	5.06
Total Expenses/bu.	6.61	5.24	5.03	4.65	5.69

Continued

Table 7. Continued.

Item	Mississippi	Monroe	Phillips	St. Francis	Average
Yield (bu.)	218	170	200	145	176
Price Received ($/bu.)	6.94	7.03	6.99	7.26	7.03
Total Crop Revenue	**1512.40**	**1194.45**	**1397.54**	**1053.25**	**1237.23**
Operating Expenses					
Seed	164.58	75.00	157.42	75.00	118.95
Fertilizers and Nutrients	160.95	305.67	243.99	276.69	227.84
Chemicals	93.63	148.49	205.68	102.50	144.95
Custom Applications	69.60	64.00	69.50	62.00	63.89
Diesel Fuel	15.61	21.12	18.97	22.32	20.35
Repairs and Maintenance	20.41	21.04	24.79	24.83	23.07
Irrigation Energy Costs	49.18	45.66	137.84	137.84	81.37
Labor, Field Activities	44.93	45.00	44.01	47.58	45.86
Other Inputs and Fees, Pre-harvest	14.49	16.15	20.07	17.38	16.64
Post-harvest Expenses	131.56	102.60	120.70	87.51	106.35
Total Operating Expenses	**764.94**	**844.73**	**1,042.98**	**853.65**	**849.27**
Returns to Operating Expenses	**747.46**	**349.72**	**354.57**	**199.60**	**387.96**
Capital Recovery and Fixed Costs	73.90	93.24	99.64	108.54	94.86
Total Specified Expenses[a]	**838.84**	**937.97**	**1,142.61**	**962.18**	**944.13**
Returns to Specified Expenses	**673.57**	**256.48**	**254.93**	**91.07**	**293.10**
Operating Expenses/bu.	3.51	4.97	5.21	5.89	4.88
Total Expenses/bu.	3.85	5.52	5.71	6.64	5.44

[a] Does not include land costs, management, or other expenses and fees not associated with production.

Table 8. Selected variable input costs per acre for fields enrolled in the 2022 Rice Research Verification Program.

County	Rice type	Seed	Fertilizers and nutrients	Herbicides	Insecticides	Fungicides and other inputs	Diesel fuel	Irrigation energy costs
Arkansas	RT 7521 FP	160.36	203.56	173.42	7.65	---	25.23	25.42
Crittenden	RT 7321 FP	160.36	202.55	126.09	7.52	21.09	17.74	137.84
Drew	DG 263 L	75.00	238.49	118.58	11.41	30.29	17.93	15.05
Jefferson	DG 263 L	66.67	164.75	166.85	---	---	16.75	45.66
Lonoke	RT 7401	136.19	253.94	91.31	---	---	27.48	137.84
Mississippi	RT 7521 FP	164.58	160.95	75.81	11.41	6.41	15.61	49.18
Monroe	DG 263 L	75.00	305.67	140.04	3.76	4.69	21.12	45.66
Phillips	RT 7521 FP	157.42	243.99	181.58	---	24.10	18.97	137.84
St. Francis	DG 263 L	75.00	276.69	102.50	---	---	22.32	137.84
Average	**---**	**118.95**	**227.84**	**130.69**	**8.35**	**17.31**	**20.35**	**81.37**

Utilization of a Single Nucleotide Polymorphism (SNP) Marker Set for Genomic Selection in Rice Breeding

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Abstract

Conventional and marker-assisted selection (MAS) approaches have been successful for new rice variety development at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC) in Stuttgart, Arkansas. However, new emerging approaches and technologies such as genomic selection (GS) hold the potential to accelerate the breeding process when using a germplasm-tailored suitable marker set. The main goal of this study was to demonstrate the efficiency of the pre-validated LSU500 U.S. Rice Panel in Arkansas germplasm. The marker set was tested on 605 genotypes from Advance Yield Trials (AYT) and Stuttgart Initial Trials (SIT) in 2021. A total of 353 single nucleotide polymorphisms (SNP) were identified as informative for the targeted germplasm set. Prediction accuracy was calculated for four traits - days to heading, height, yield, and percentage head rice yield. This report presents the preliminary results of prediction accuracies obtained and provides insights on the potential usefulness of the final marker set in the Arkansas Rice Breeding Program.

Introduction

Genomic selection (GS) is a breeding scheme that arises as an alternative to marker-assisted selection (MAS). It has been proven to increase breeding efficiency by improving gain per selection per unit time. This breeding scheme uses genome-wide DNA markers to predict which individuals of a breeding population are most valuable to use as parents for the next round of crossing based on their genomic estimated breeding values (GEBVs) (Meuwissen et al., 2001). These values are estimated using a model that establishes the relationship between genome-wide markers and the phenotypic values of the individuals under selection. The model is developed from a training population that resembles the population undergoing selection (testing population). The training population is genotyped and phenotyped, whereas, the testing population is only genotyped. The testing population genotypes are then entered into the model to calculate the GEBVs of all the individuals in the population, including those with no phenotypic information. In contrast to MAS which uses DNA markers that target genes with major effects, GS uses DNA markers regardless of the effect size, thus, avoiding bias. Statistical and machine-learning approaches are used to fit all marker effects in a single model (Meuwissen et al., 2001; Lorenz et al., 2011). Genetic gain from selection under GS is proportional to the accuracy of the GEBVs. Essentially, if the accuracy of prediction is considerably high, GS can reduce the breeding cycle time by increasing the number of high-performing offspring in a breeding population (Bernardo, 2009; Heffner et al. 2009). Although GS was initially implemented in dairy cattle breeding, it has proven successful in crop breeding. Up to now, maize and wheat breeding programs have implemented the GS approach into their routine breeding pipeline. For both crops, high GEBV accuracy for grain yield and other complex traits has been reported using cross-validation experiments (Lorenzana et al. 2009; Guo et al., 2012). For other crops such as sugarcane, sugar beet, and cassava, preliminary experiments of GS have also been reported (de Oliveira et al., 2012; Ly et al., 2013; Wurschum et al., 2013). In rice, great efforts are being made toward the identification of germplasm-tailored marker sets that will allow breeders to successfully introduce genomic selection in routine breeding pipeline.

Procedures

Plant Material and Genotyping

In 2021, a total of 605 lines were genotyped using the LSU500 (550 SNP markers) US Rice Panel (Cerioli et al., 2022) through the genotyping service provider AgriPlex Genomics (https://agriplexgenomics.com). The germplasm set consisted of 76 conventional non-aromatic, 38 aromatic, and 57 Clearfield lines from advanced yield trials (AYT), and 189 conventional non-aromatic, 62 aromatic, and 183 Clearfield lines from Stuttgart Initial Trials (SIT).

Phenotypic Data

Phenotypic data were collected from 7 trials under different stages of testing. From these, three were AYTs and four were SITs. All AYTs were drill-seeded as 12 ft long and 5 ft wide plots, whereas, SIT plots were 7 ft long and 5 ft wide. Each trial was grown in a randomized complete block design at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC), near Stuttgart, Ark. in 2021. All entries were replicated three times within each trial in a randomized complete block design (RCBD). A single pre-flood of 130 lb/ac nitrogen in the form of urea was applied to dry soil when the plants reached 4 to 5 leaf stage before permanent flood was established. Days to heading were recorded as the number of days between the day of emergence and the day when 50% of the plot had exerted panicles. At maturity, plant height was

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recorded (in centimeters) from the soil surface to the panicle tip. Grain yield was determined by harvesting the entire plot with a Wintersteiger combine, and an integrated HarvestMaster system was utilized to collect grain weight and moisture content. For the yield determination, the moisture content of each plot was adjusted to 12%. A clean 100g rough rice sample was collected from each plot and milled using the Zaccaria sample mill. Head rice yield was expressed as the mass percentage of whole kernels.

Genetic Data Quality Assessment

Filtering of the Marker Set. JMP® Genomics v. 9.1 (SAS Institute Inc., Cary, N.C.) was used to filter the genetic data. Single nucleotide polymorphisms with a proportion of missing genotypes > 10% across all genotypes were removed. Any individual with missing data >10% across all SNPs was also removed. Finally, SNP markers with minor allele frequency (MAF) < 0.1 were dropped from the analysis. After these filtering steps, the resulting data set was composed of 605 genotypes and 353 SNPs.

Data Analyses

Data analyses were performed using JMP® Genomics v. 9.1 (SAS Institute Inc., Cary, N.C.). Principal component analysis (PCA) was conducted to detect for population structure of the genotyped germplasm set. Furthermore, the identity-by-state (IBS) analysis was conducted to identify the nearly identical individuals (duplicates) in the germplasm set that were revealed by the SNP marker set. Genomic best linear unbiased predictor (GBLUP) model was used to test for the predictive ability.

Results and Discussion

Subpopulation and Family Structure

A total of 353 informative SNP markers distributed across the rice genome were identified in the LSU500 US Rice panel (Fig. 1A). The MAF of this final marker set ranged from 0.1 to 0.498 with a mean of 0.277 (Fig. 1B). The 353 SNP informative markers were used to determine subpopulation and family structure of the germplasm set based on principal component analysis and IBS analysis. Two principal components explained ~70% of the variation in the germplasm set. Principal component (PC) 1 accounted for 43.4% of the variation in the training population whereas PC2 explained 26.4% (Fig. 2). These analyses corroborated the presence of two main subpopulations (Fig. 3). From these, 84% belonged to the *tropical japonica* subgroup, whereas, 16% belonged to the *aro* subpopulation.

Genomic Selection and Predictive Modeling

Genomic best linear unbiased predictor (GBLUP) was used to determine the predictive ability of four traits including days to heading, plant height, grain yield, and head rice yield. This genomic selection method was chosen based on its demonstrated success in accurately predicting genomic estimated breeding values (GEBVs) in other important crops. For each trait, the accuracy of prediction was determined by the correlation between the phenotypic value and the predicted value. As shown in Fig. 4, prediction accuracies resulted in 0.75, 0.67, 0.85, and 0.77 for days to heading (Fig. 4A), plant height (Fig. 4B), yield (Fig. 4C), and head rice yield (Fig. 4D), respectively. These prediction accuracies were high as compared to others reported in the literature for the same traits. Most individuals in the training set were developed from AR elite lines that have been used for several years for new variety development, therefore, some factors that could have contributed to these results were the high levels of inbreeding and high heritability. Heritability values equal to 0.64, 0.44, 0.56, and 0.79 were obtained for days to heading, height, yield, and head rice yield, respectively.

Practical Applications

This study is an attempt to demonstrate the usefulness of genomic selection in an applied rice breeding program. The ultimate goal of this approach is to increase selection accuracy, selection intensity, and reduction of the cycle time during variety development. Identification of a marker set that accurately predicts traits of interest is the first step toward the implementation of genomic selection. Accuracy of predictions obtained in this preliminary study provides insights into the potential of the marker set to be used in the Arkansas rice breeding program to speed up the breeding process.

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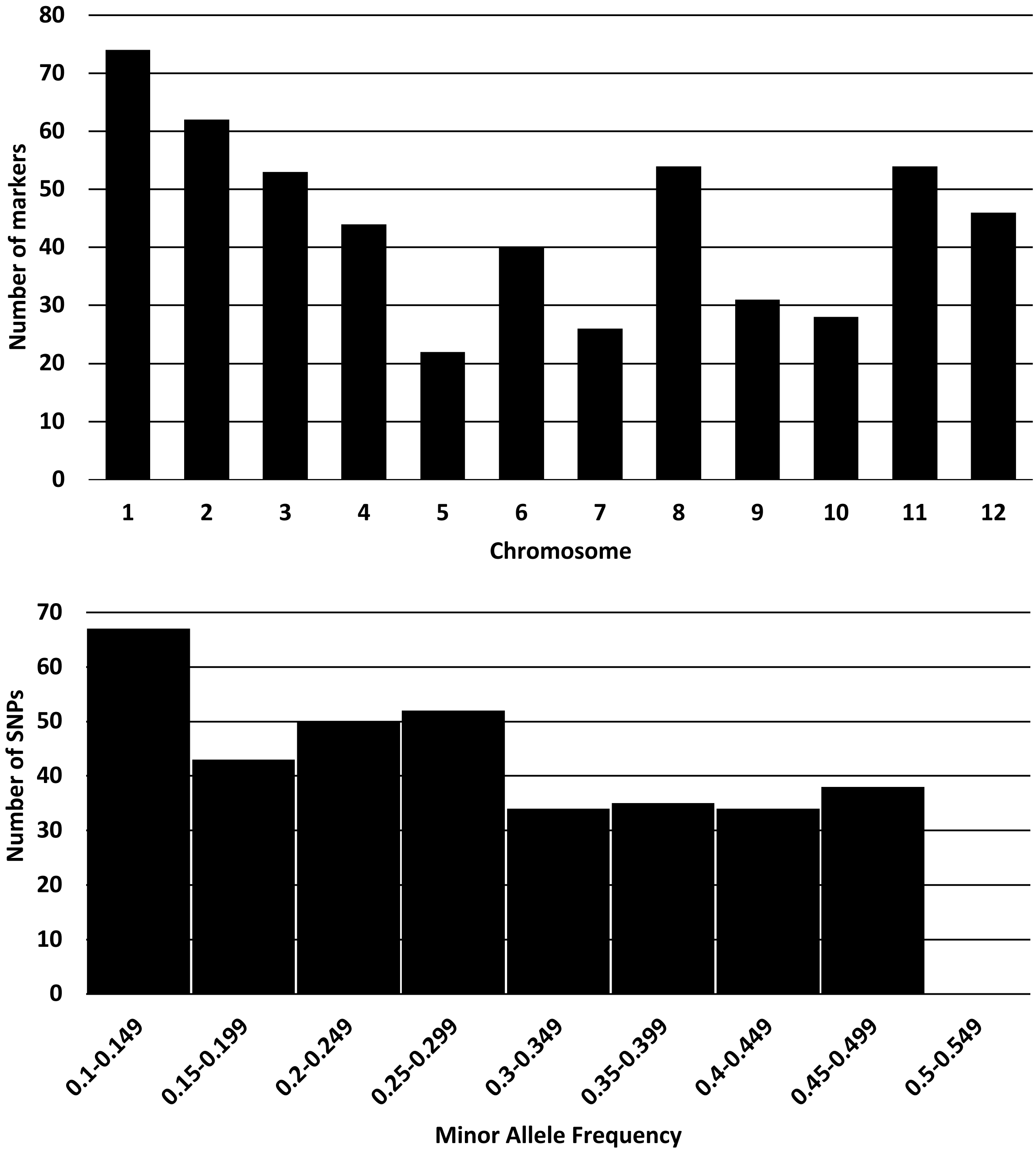

Fig. 1. Marker set properties A) number of significant markers (minor allele frequency, MAF, between 0.1–0.5) per chromosome. B) distribution of single nucleotide polymorphism (SNP) markers per allele frequency across the training population.

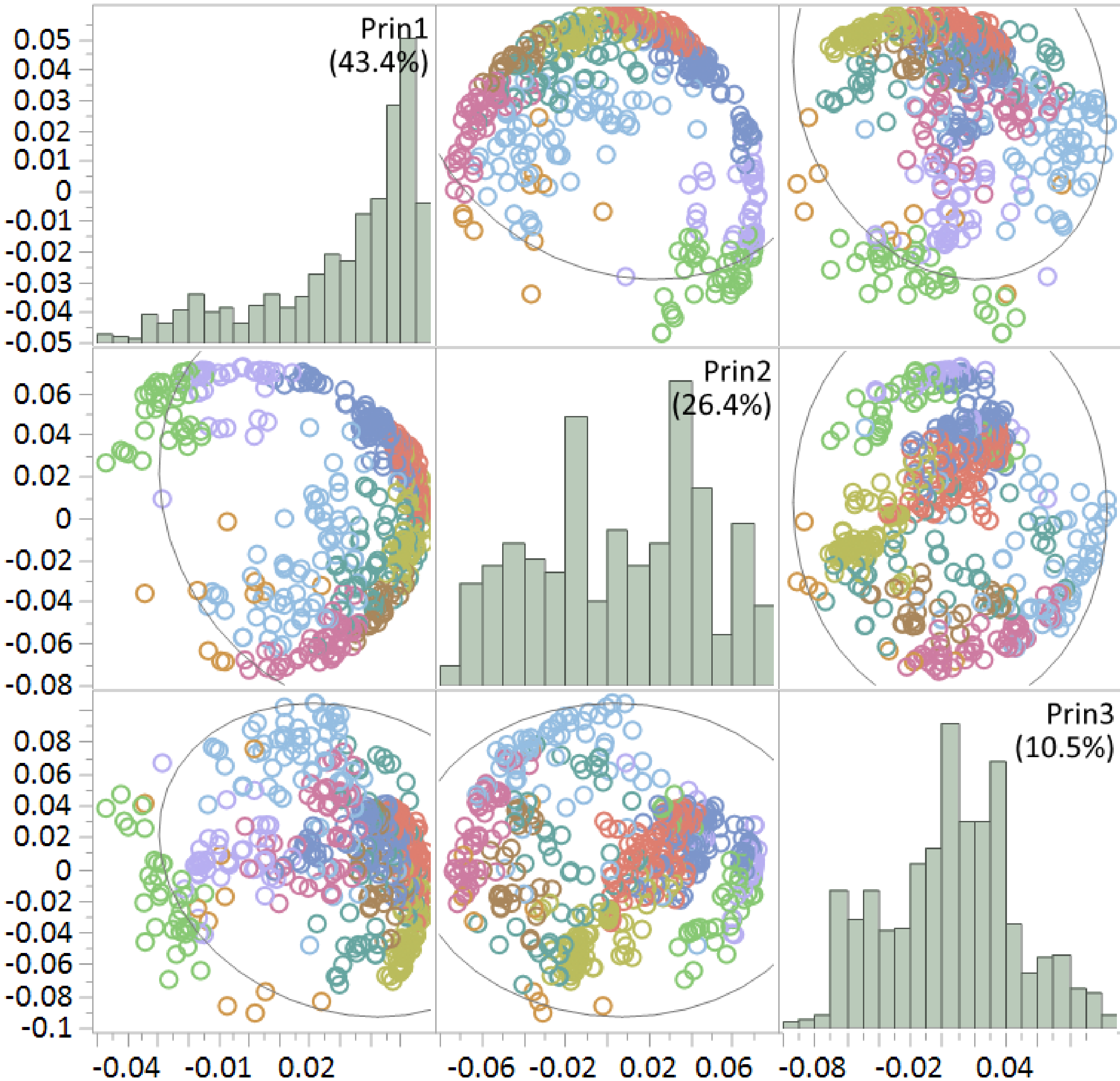

Fig. 2. Principal component analysis of the training population using 353 single nucleotide polymorphism (SNP) markers.

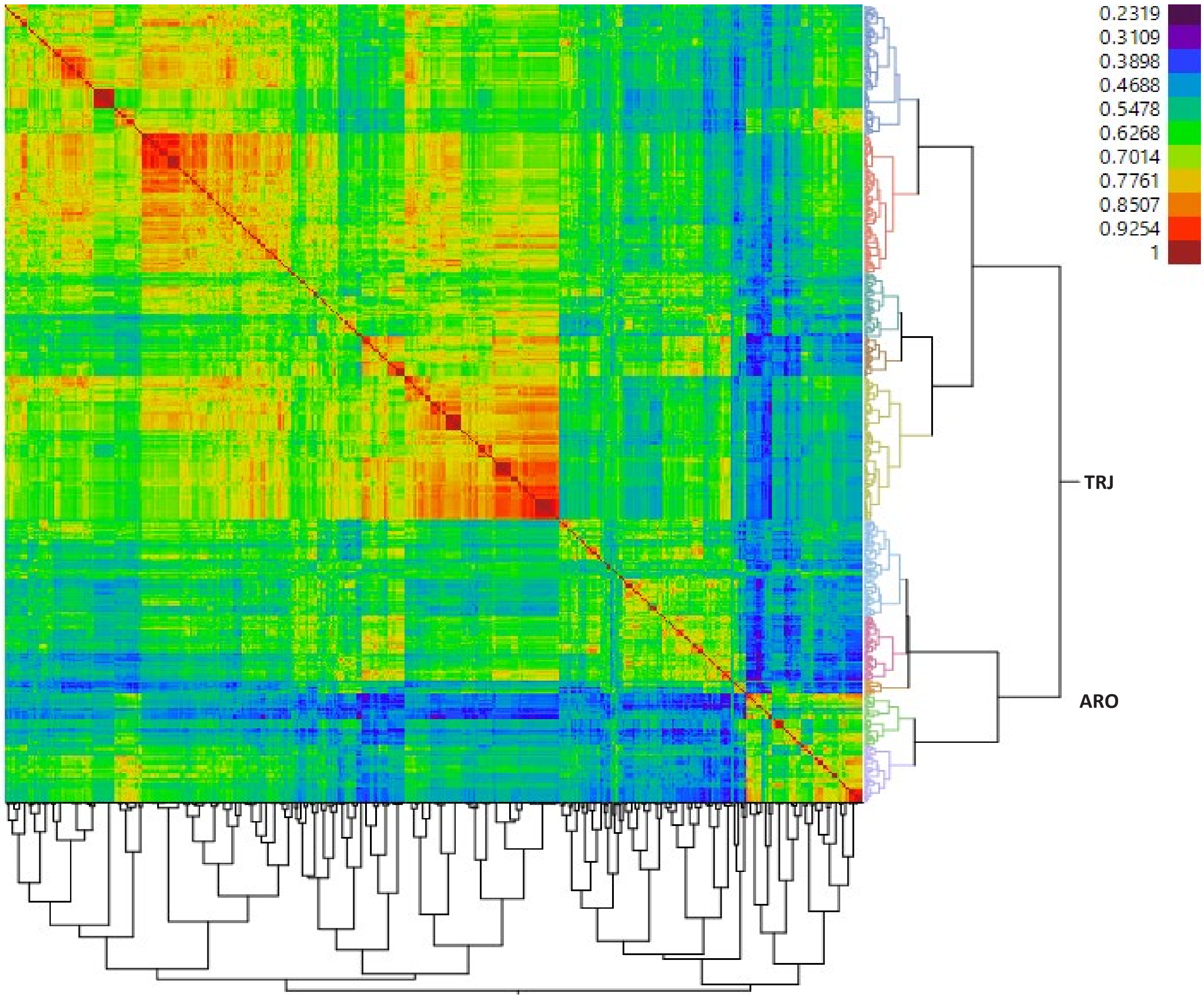

Fig. 3. Heatmap and dendrogram of identity by state analysis of the training population. TRJ = *tropical japonica* subpopulation, ARO = *aromatic* subpopulation.

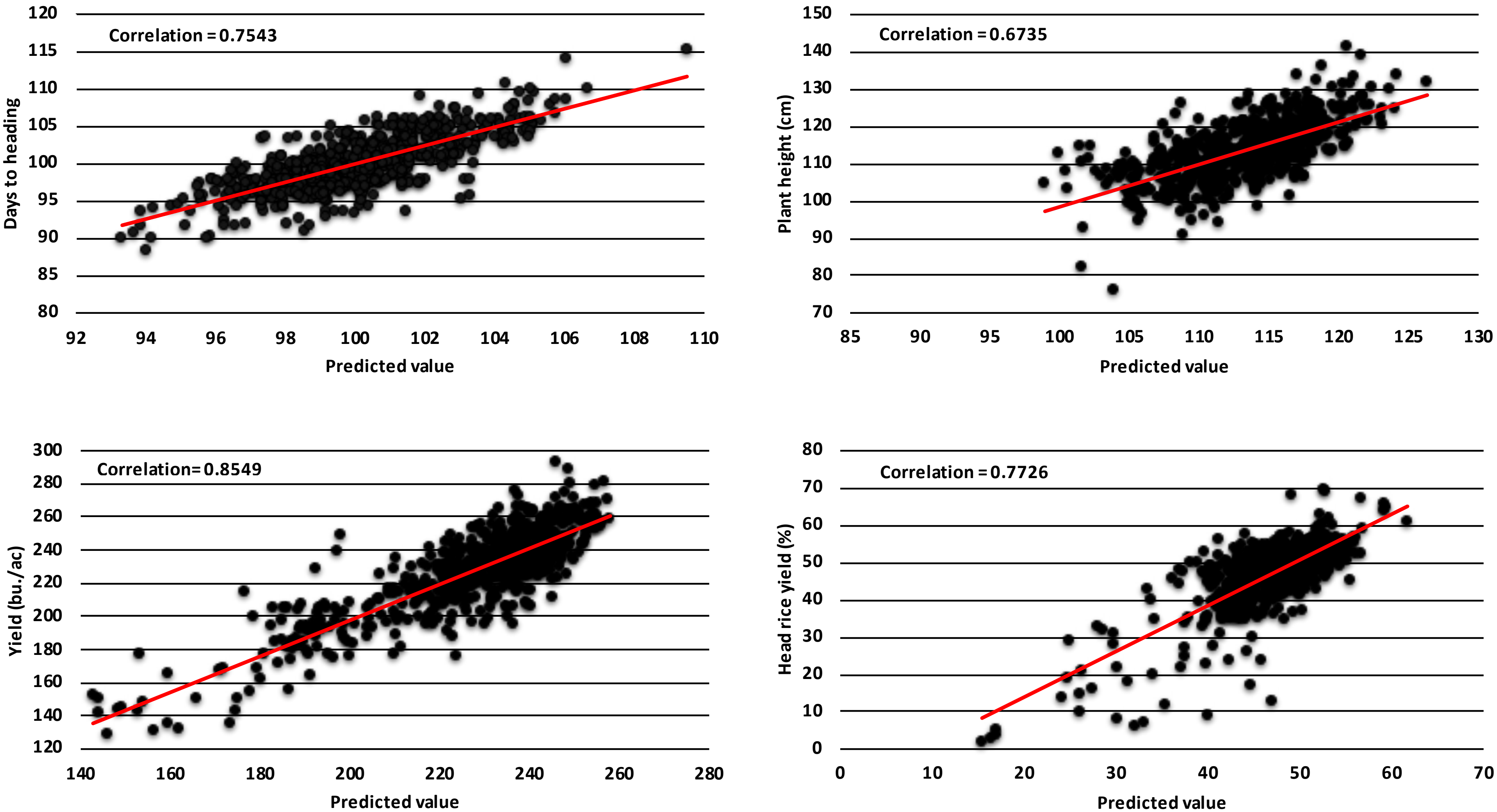

Fig. 4. Correlation of true phenotypic values and genomic estimated breeding values for A) days to heading, B) plant height in centimeters, C) yield in bushels/acre, and D) head rice yield as mass percentage of whole kernels.

Preliminary Quantitative Trait Loci (QTL) Development for Improving Performance of Arkansas Rice Cultivars Under High Night Temperature Conditions

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Abstract

High night temperature stress in rice greatly reduces yield by reducing spikelet fertility and other yield-related traits. In our study, we used 297 $F_{2.4}$ recombinant inbred lines (RILs) from a Diamond x N22 population and genotyped them using 1016 SNPs from the IRRI RiCA panel (Arbelaez et al., 2019). We detected a significant quantitative trait loci (QTL) for percent-filled grains on chromosome 12 with 9.9% phenotypic variation explained (PVE) and two minor QTL on chromosome 6 (6.3% and 5.0% PVE). Additionally, two QTL were detected in chromosome 4 for the number of tillers (6.0% and 5.0% PVE). Significant QTL for other agronomic traits such as chlorophyll content, number of branches on panicles, days to harvest, stalk diameter, height, exertion of panicles, length of flag leaf, and presence of awns were detected in chromosomes 1, 2, 3, 4, 5 and 7.

Introduction

Nagina 22 (N22) is a well-known *Aus* type rice with heat and drought tolerance (Bahuguna, et al., 2015, Jagadish, et al., 2007). Currently, no U.S. rice varieties have high-nighttime temperature (HNT) tolerance similar to N22. This is due in part to the difficulty of performing experiments in controlled environments that simulate high night temperature conditions and allow screening as well as the lack of markers to transfer the trait from N22 using marker-assisted selection. Additionally, most literature on quantitative trait loci (QTLs) that maps the donor N22 are from N22 x indica populations, and information is lacking for tropical japonica or temperate japonica crosses of U.S. rice genetic background. In this preliminary QTL study, we generated F_4 recombinant inbred lines (RILs) from a cross between parents Diamond and N22 and identified QTLs that are significantly associated with yield-related traits under high-night temperatures.

Procedures

We generated 700 F_4 RILs from a Diamond x N22 population. We also generated 400 RILs from a ZHE 733 x N22 population. A random selection of 310 RILs was taken from each population and grown in individual pots. In this report, we focus solely on the Diamond x N22 population and primarily on QTL useful for selection for improved breeding efficacy.

Seedlings were raised in the greenhouse and grown in 4 × 4 × 10 in. (length by width by depth) rectangular pots containing a 3:2:1 ratio of silt loam topsoil, potting mix (BactoPro), and sand. Two seeds per RIL were sown in each pot and thinned to one seedling, two weeks after sowing (WAS). Fertilization was administered per pot with the following volume, type and schedule: 50 mL of Peter's solution (20-20-20) (460 g diluted in 25 gal water) at three WAS; 50 mL of Urea (46-0-0) (0.025 lb N/gal) at five WAS; and 50 mL of Urea (46-0-0) (0.0083 lb N/gal) at the R2 stage. The relative humidity (RH) inside the greenhouse was maintained between 70% and 75 %. Day and night temperatures in the greenhouse were maintained at 86.0–89.6 °F (30–32 °C) and 73.4–78.8 °F (23–26 °C), respectively. Natural sunlight served as the major light source in the greenhouse supplemented with metal halide lighting at a minimum 13-hour day length. Plants were screened individually, and upon reaching the R2 growth stage (Counce et al., 2000), each RIL was transferred to the controlled climate in the growth chambers maintained at HNT conditions.

The diurnal environmental conditions for the growth chambers were similar to those of a July day in Arkansas. Growth chamber temperatures were tightly controlled to obtain temperatures ranging from a minimum to a maximum and back down to a minimum during each 24-hour cycle (Table 1). The variation within each range was usually within 0.1 °C from the setpoint. Large growth chambers were used and night temperatures gradually declined to a low of 82.4 °F (28 °C), which lasted from 20:00 to 6:00. Day temperatures in the growth chambers were increased gradually from 82.4 °F (28 °C) at 6:00 AM to 91.4°F (33°C) at 12:00.Relative humidity (RH) was maintained at 70–75%, irradiance between 36 to 112 µmole/ft^2/s (390 to 1200 µmole m^2/s) and CO_2 at 550 ppm.

At maturity, plants were harvested and data gathered on the main stem including largest and second-largest tillers. Data on agronomic traits include percent filled grains, number of tillers, number of primary branches on the panicles, plant height (cm), days to harvest, chlorophyll content, stalk diameter (mm), exertion of panicle, length of flag leaf, and presence of awns. Leaf samples were genotyped using the 1k IRRI RiCA V.4 SNP panel. A total of 237 markers were found to be polymorphic between the parents Diamond and N22.

QTL were mapped using QTL IciMapping Version 4.2 (Meng, et, al. 2015). The mapping function used is Kosambi and the prob-

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ability of stepwise regression was set at 0.001. The confidence interval (CI) of each QTL was determined by logarithm of odds (LOD) > 2.5. The physical map was generated using JMP genomics Ver. 9 (SAS Institute, Inc., Cary, N.C.).

Results and Discussion

Frequency distribution of percent filled grains in the F_4 RIL population showed slightly higher individuals (32) on the 0–10% range but overall indicates a normal distribution. The mean for percent filled grain was 48.8, the standard deviation was 25.0, the standard error of the mean was 1.45, the upper 95% mean was 51.6, and the lower 95% mean was 45.9. In the number of tillers, the distribution is skewed to the left with more individuals (277) from the range of 1 to 8 tillers and fewer (20) in the range of 9–13 tillers. The mean for tiller number was 5.14, the standard deviation was 1.92, the standard error of the mean was 0.11, the upper 95% mean was 5.36 and the lower 95% mean was 4.92 (Fig. 1).

Our preliminary QTL mapping using inclusive composite interval mapping (ICIM) showed significant QTL on ten traits that were measured. Percent filled grains is one of the major traits that affects yield under high-night time temperatures and we have found QTL in the interval between chr12_17571574 and chr12_19522102 with 9.9 phenotypic variation explained (PVE) in chromosome 12. Additionally, two minor QTL were detected in chromosome 6 between chr06_3598843 and chr06_3951547 and between chr06_26139965 and chr06_27761109 with 6.3 and 5.0 PVE, respectively. Tillering ability which is measured by the number of tillers is a trait that indirectly influences yield (Hanada 1993). Two QTL were found on chromosome 4 in the regions between chr04_31509863 and chr04_14229856 and between chr04_14229856 and chr04_22435296 (Table 2). Physical map of the QTL for both percent filled grains and number of tillers are shown in Fig. 2. Two major QTL (>10 PVE) were found for height and chlorophyll content in the same marker interval between chr01_37274755 and DTY1-1_2. Additional QTL found for other traits include: number of branches on the panicle located on chromosomes 2, 6 and 3; days to harvest on chromosomes 1, 2 and 3; stalk diameter on chromosomes 2 and 5; exertion of panicle on chromosomes 1 and 4; length of flag leaf on chromosomes 1 and 4; and presence of awns on chromosomes 7 and 4 (Table 2).

Practical Applications

These preliminary findings are part of a concerted effort to improve the yield and quality of Arkansas rice varieties under high night temperature conditions. The work is aimed to complement and enhance the extensive, multifaceted efforts of the Arkansas rice breeding program.

Acknowledgments

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Table 1. Controlled climate (growth chamber) setpoints for each 24-hour cycle.

Time	Temperature (°F)	Humidity (%)	CO_2 (ppm)	Light 1[a]	Light 2	Light 3
06:00:00	82	70	550	010	010	55
08:00:00	86	70	550	111	111	55
08:30:00	86	70	550	111	111	60
09:00:00	86	70	550	111	111	65
09:30:00	86	70	550	111	111	70
10:00:00	91	70	550	111	111	75
10:30:00	91	70	550	111	111	85
11:00:00	91	70	550	111	111	95
14:00:00	91	70	550	111	111	95
14:30:00	91	70	550	111	111	90
15:00:00	91	70	550	111	111	85
15:30:00	91	70	550	111	111	80
16:30:00	91	70	550	111	111	75
17:00:00	86	70	550	111	111	70
17:30:00	86	70	550	111	111	65
18:00:00	86	70	550	111	111	60
18:30:00	86	70	550	111	111	55
19:00:00	86	70	550	101	101	55
19:30:00	86	70	550	010	010	55
20:00:00	82	70	550	000	000	95

[a] Light in the chambers is provided by banks that each contain three metal halide bulbs and three high pressure sodium bulbs. Each bulb can be on (1) or off (0). Light 1 and Light 2 denote the status of the metal halide and high pressure sodium lamps, respectively for each bank of bulbs. Light 3 is the percent power supplied to all bulbs. Maximum irradiance in the chambers at 3 feet height is approximately 1200 umoles/m$^{2/}$s with Light 1 and Light 2 set at 111 (all bulbs on) and Light 3 set at 95%.

Table 2. Selected significant quantitative trait loci detected in marker intervals for different agronomic traits at logarithm of odds (LOD >3) and phenotypic variation explained (PVE > 3).

Trait Name	Chr[a]	Pos (cM)[b]	Left Marker	Right Marker	LOD	PVE
Percent Filled Grains	12	34	chr12_17571574	chr12_19522102	8.91	9.93
	6	14	chr06_3598843	chr06_3951547	5.55	6.29
	6	86	chr06_26139965	chr06_27761109	4.35	4.99
Number of Tillers	4	71	chr04_31509863	chr04_14229856	7.90	6.06
	4	89	chr04_14229856	chr04_22435296	7.54	5.81
Number of Branches	2	108	chr02_25415397	chr02_28049479	7.41	8.66
	6	10	chr06_1768006	chr06_3598843	5.19	5.92
	3	37	chr03_28851199	chr03_25259336	3.78	5.76
Height (cm)	1	142	chr01_37274755	DTY1-1_2	19.56	18.64
	5	5	chr05_28101376	chr05_27627633	5.72	5.10
	3	2	chr03_34476308	chr03_31614921	4.54	4.38
	6	11	chr06_1768006	chr06_3598843	4.62	4.33
Days to Harvest	2	143	chr02_30530432	IRGSP1_C02_34852782	3.74	7.75
	1	49	chr01_7068516	chr01_8760562	6.19	7.34
	1	138	chr01_35794891	chr01_37274755	3.94	4.53
	3	91	chr03_9375374	chr03_8711509	3.36	3.83
Chlorophyll	1	141	chr01_37274755	DTY1-1_2	12.99	16.32
	5	25	chr05_22711811	chr05_21494622	7.16	8.45
	4	134	chr04_22435296	MSU7_4_19796129	7.05	8.08
Stalk Diameter (mm)	2	108	chr02_25415397	chr02_28049479	3.81	5.42
	5	27	chr05_22711811	chr05_21494622	3.65	4.30
Exertion of Panicle	4	72	chr04_31509863	chr04_14229856	5.97	6.19
	1	91	chr01_23240729	chr01_5064126	5.07	5.32
Length of Flag Leaf	4	84	chr04_14229856	chr04_22435296	3.02	5.24
	1	95	chr01_23240729	chr01_5064126	5.88	4.83
Presence of Awns	7	65	NAS3_2	chr07_514293	31.69	8.10
	4	56	chr04_31509863	chr04_14229856	19.27	7.35

[a] Chr = chromosome.

[b] Pos (cM) = Position in centimorgan.

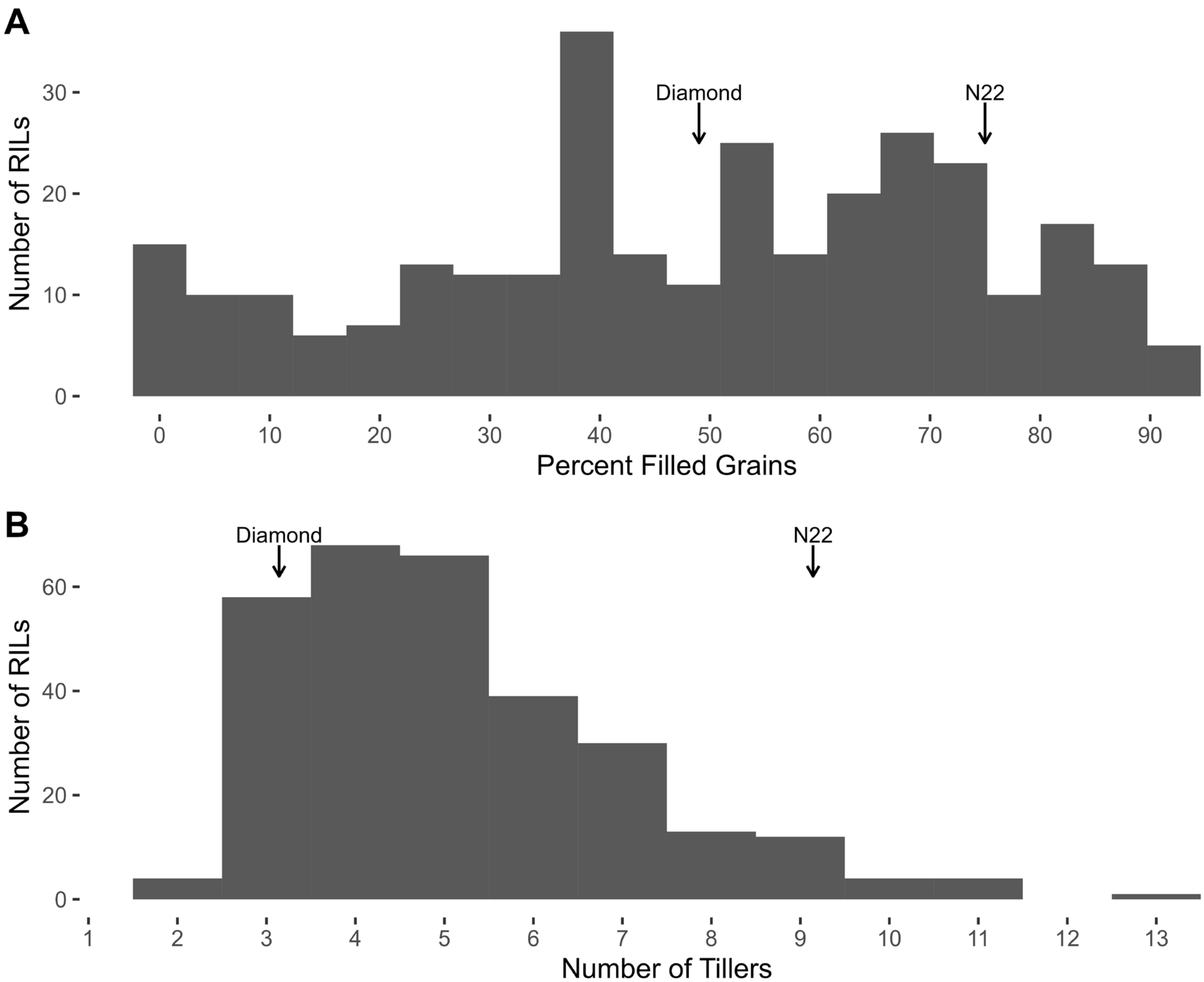

Fig. 1. Frequency distribution of percent filled grains (A) and number of tillers (B) in 299 F_4 recombinant inbred lines (RILs) from Diamond x N22 population.

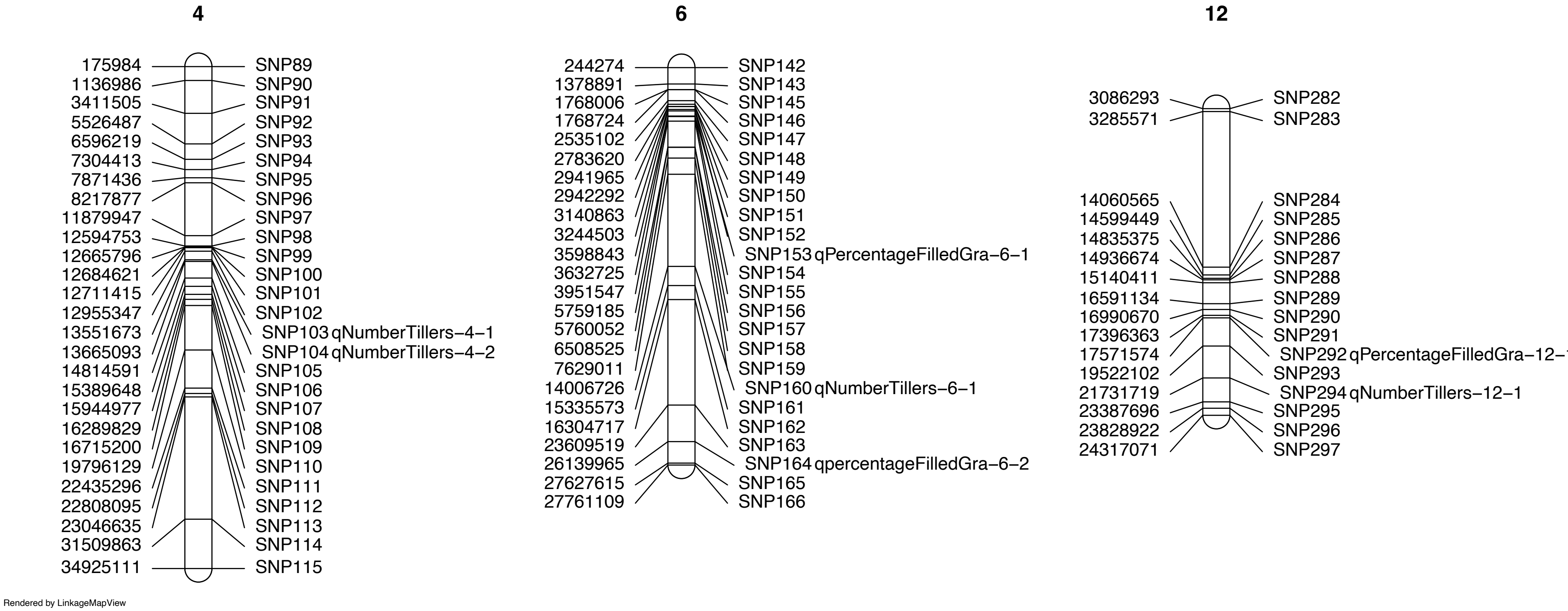

Fig. 2. Physical map of rice chromosomes 4, 6, and 12 showing relative positions of quantitative trait loci (QTL) for percent filled grains (qPercentageFilledGra) and number of tillers (qNumberTillers).

Evaluation of Conventional, Clearfield, and Aromatic Experimental Long-Grain Rice Lines in Four Arkansas Locations

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Abstract

The Arkansas Long Grain and Aromatic Rice breeding program is actively developing and improving rice varieties that are widely adopted in the U.S. Mid-South. Strict evaluations on desirable characteristics are conducted in different phases of the breeding program. Characteristics that are important include high grain yield potential, excellent milling yields, good plant stature, pest and disease resistance, and superior grain quality (i.e., low percent chalk, cooking, processing and eating). We conducted an advanced yield trial of conventional, herbicide-tolerant Clearfield and conventional aromatic long grains at four locations in Arkansas to identify potential lines to be advanced and possibly released as varieties in the future. We have identified several lines that are comparable or better in grain yield, milling yield, and other agronomic characteristics than existing checks in some or all four locations. These lines will be advanced to another multi-location yield test in the following year to confirm stability across years and locations.

Introduction

The rice breeding and variety development program in Arkansas evaluates lines with good agronomic characteristics, high grain yields, excellent milling yields and good grain qualities. Successful varietal release necessitates extensive testing across years and locations. Recent varieties released in the breeding program such as CLL18 (Moldenhauer et al., 2022) and ARoma 22 (Wisdom, et., al. 2022) have undergone similar testing during early and late-stage yield tests. Similarly, before a breeding line is moved to the pre-commercial release trials such as in Arkansas Rice Variety Advancement Trials (ARVAT) and Arkansas Rice Performance Trials (ARPT), up to a hundred lines with checks are evaluated at late-generation testing in multiple locations in Arkansas. These experimental lines are in the F_5 generation or later while simultaneously advancing and seed increasing. The top 10% of the best lines are then identified based on high grain yield with acceptable agronomic characteristics and better milling yield.

Procedures

The overall experiment has a total of 99 entries in three replications in four locations consisting a total of 1,188 plots. The trials are separated in three groups: Conventional Long Grain Advanced Yield Trial (22LGAYT) made up of 49 conventional lines with 6 checks; Clearfield Long Grain Advanced Yield Trial (22CLAYT) made up of 36 clearfield lines with 4 checks; and Aromatic Advanced Yield Trial (AROAYT) made up of 14 aromatic lines with 3 checks. These were planted in 4 different locations in Arkansas. The locations are: University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC) near Stuttgart, Ark.; Pine Tree Research Station (PTRS) at Colt, Ark.; Northeast Rice Research and Extension Center (NERREC) at Harrisburg, Ark.; and Northeast Research and Extension Center (NEREC) at Keiser, Ark. Seven of the lines were previously planted in Uniform Regional Rice Nursery (URRN) in 2021 or earlier. The experimental design used is a randomized complete block design (RCBD) with three replicates. The plots measured 20 ft long with 7.5-inch row spacing and were drill seeded at 70 lb/ac seeding rate using an Almaco 8-row planter. Seeds were not treated with any chemicals and the plants were not sprayed with fungicides to allow natural infection and determine performance under the natural environment. A single pre-flood of 130 lb/ac of nitrogen in the form of urea was applied to dry soil when the plants reached 4 to 5 leaf stage before permanent flood was established after 1–2 days. Due to malfunctioning of the gandy fertilizer applicator, only 110 lb/ac of nitrogen was applied in NEREC. Before harvesting, the plots were trimmed on both ends to 16 ft and only the middle 6 rows were harvested to minimize border effects on yield using Wintersteiger Quantum plot combine (Wintersteiger Inc USA. Salt Lake City, Utah). The plot combine integrated Harvest Master system automatically measured plot weights and moisture. Grain yields were calculated as bushels per acre adjusted to 12% moisture content. Approximately 300 g of rough rice were collected from each of the harvested plots for milling samples and a subsample of 100 g from cleaned seeds was used in milling using a Zaccaria PAZ-100 sample mill (Zaccaria, Limeira, Brazil). Other traits such as height (cm) and days to 50% heading were also collected. Data were analyzed using the analysis of variance (ANOVA) in each

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location on each trial type using Genovix plant breeding software (Genovix, Canada). The means were separated by Fisher's least significant difference at a probability of ≤0.05.

Results and Discussion

Conventional Long Grain (22LGAYT)

Significant differences were detected in grain yield on each of the four locations. The NEREC location has less grain yield overall, which can be attributed to less nitrogen applied. The highest-yielding line at the RREC is entry 126 with 215 bu./ac; at PTRS, it is entry 136 with 206 bu./ac; and at NERREC and NEREC, is the check variety Ozark with 211 and 177 bu./ac, respectively. Overall mean yields for all four locations shown in the top 5 are Ozark entries 121, 136, 133, and 135 with average yields of 200, 198, 196, 192, and 191 bu./ac, respectively. Except for NERREC, the days to heading are all significantly different in each of the four locations. The average days to heading in all locations showed entries 125 and 140 being the earliest with 88 days which is comparable to check Ozark and Diamond with 88 and 89 days, respectively (Table 1). The height in each location showed statistically significant differences. The average height showed Ozark with 104 cm compared to entries 121, 136, 133, and 135 with heights of 98, 105, 102, and 107, respectively. Milling yields are significantly different across four locations. The top 5 entries vary in both % total and % head rice yield in each location but the average milling yields in all locations are closer to each other. Average milling yields (%total/%head rice) for the top 5 varieties are 71/55 (Ozark), 70/55 (121), 70/57 (136), 70/51 (133), and 69/52 (135) (Table 2).

Clearfield Long Grain (22CLAYT)

Statistical differences were detected in each location for grain yield in 22CLAYT. The top 5 highest-yielding entries in all four locations are 1315, 1310, CLL18, 1307, and CLL16 with 198, 197, 196, 193, and 192 bu./ac, respectively. The days to heading on 3 locations showed significant differences and no differences were detected in NERREC. Entries 1315, 1310, 1307 have 87, 91, and 90 days compared to check CLL16 and CLL18 with 93 and 89 days, respectively (Table 3). Average height in four locations showed entries 1315, 1310, 1307 are slightly taller than one of the checks with 117, 109, and 115 cm, while checks CLL18 and CLL16 are 107 and 112 cm in height, respectively. Average milling yield as % total/% head in all four locations showed 1315 slightly higher in % total rice and comparable to CLL16 and CLL8 in % head rice. Entries 1315, 1310, 1307 have 72/56, 69/57 and 68/53 compared to CLL16 with 70/56 and CLL18 with 68/55 of % total/% head rice, respectively (Table 4).

Aromatic Rice (22AROAYT)

Overall grain yields of the experimental entries in 22 AROAYT are higher compared to the check in most locations. There are no significant differences in grain yield observed in PTRS and NEREC, and statistically significant differences were observed in RREC and NERREC. Overall mean yields in four locations showed the top three highest-yielding entries are 3708, 3707, and 3706 with 182, 181, and 181 bu./ac, respectively. The top entries have a yield advantage of about 20 bu./ac compared to 160 and 159 bu./ac of ARoma 22 and ARoma 17, respectively. Significant differences were observed in days to heading at three locations (RREC, PTRS, and NERREC), while no significant differences were observed at the NEREC location. Entries 3708, 3707, and 3706 have 89, 90, and 88 days to head compared to ARoma 22 and ARoma 17 with 88 and 90 days average on all four locations (Table 5). The heights of these experimental entries are shorter than ARoma 22 and ARoma 17. Entries 3708, 3707, and 3706 have 102, 100, and 101 cm compared to 113 and 108 cm of ARoma 22 and ARoma 17, respectively. A negative trade-off was observed in the head rice yield of the top 3 highest-yielding entries. Overall milling yields of experimental lines are comparable to ARoma 22 but less than the check ARoma 17. Entries 3708, 3707, and 3706 have 68/49, 68/50, and 68/52 compared to 68/52 and 69/57 %total/%head rice in ARoma 22 and ARoma 17, respectively (Table 6).

Practical Applications

Ten lines from 22LGAYT, 9 from 22CLAYT and 2 aromatic lines from 22AROAYT were selected to advance for the 2023 Arkansas Variety Advancement Test (ARVAT) based on high grain yield, superior or acceptable milling yield and other agronomic characteristics. Two lines from 22LGAYT, one from 22CLAYT, and one from 22AROAYT from the aforementioned entries were also advanced to the 2023 URRN trials to be conducted in Arkansas, Louisiana, Mississippi, and Texas. The selected lines have the potential to be released as future varieties or will be recycled back to the breeding program as parents to generate new populations.

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Table 1. Yield (bu./ac) and days to heading of selected 10 high-yielding lines and two checks in the 2022 Long Grain Advanced Yield Trial (22 LGAYT) conducted at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC) at Stuttgart, Pine Tree Research Station at (PTRS) at Colt, Northeast Rice Research and Extension Center (NERREC) at Harrisburg, and Northeast Research and Extension Center (NEREC) at Keiser.

			Yield					Days to heading				
Entry	**Variety**	**Pedigree**	**RREC**	**PTRS**	**NERREC**	**NEREC**	**Mean**	**RREC**	**PTRS**	**NERREC**	**NEREC**	**Mean**
			-------------------------(bu./ac)-------------------------									
146	OZARK		210	202	211	177	200	88	86	88	91	88
121	STG19L-098	19991516/19951094//RNS3/…	213	205	209	164	198	89	89	90	94	90
136	STG20L-196	TGRT/6/91642//KATY/NWBT/…	212	206	208	157	196	92	88	89	97	91
133	STG20L-243	LGRU//KATY/STBN/3/LGRU/…	202	198	197	171	192	88	88	90	91	89
135	STG20L-264	DMND/8/19991516/19951166…	210	191	200	162	191	91	89	90	99	92
130	STG19L-094	19991516/19951094//RNS3…	204	202	199	157	191	90	88	92	94	91
144	STG20L-139	KATY/NWBT//L201/7402003….	208	194	207	152	190	89	89	89	98	91
125	STG19L-002	IRGA409/RXMT/5/NWBT/3….	196	197	207	160	190	87	87	88	92	88
108	STG18L-106	IRGA409/RXMT/5/NWBT/3/…	202	204	195	156	189	87	85	88	90	87
140	STG20L-019	19991516/19951094//RNS3..	205	192	203	157	189	87	86	88	91	88
126	STG17L-144	IRGA409/RXMT/5/NWBT/3…	215	188	189	161	188	88	88	89	96	90
147	Diamond		202	196	202	149	188	88	86	87	93	89
Entry (Pr > F)			0.00[a]	0.00[a]	0.00[a]	0.00[a]		0.00[a]	0.00[a]	0.45[b]	0.00[a]	
LSD			15.61	7.25	16.84	17.31		3.06	1.30	3.40	3.61	
% CV			6.08	2.86	6.54	8.47		2.60	1.09	2.82	2.79	

[a] Highly significant at *P*-value ≤ 0.01.

[b] Not significant.

Table 2. Height (cm), % head rice yield and % total rice of selected 10 high yielding lines and two checks in the 2022 Long Grain Advanced Yield Trial (22 LGAYT) conducted at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC) at Stuttgart, Pine Tree Research Station at (PTRS) at Colt, Northeast Rice Research and Extension Center (NERREC) at Harrisburg, and Northeast Research and Extension Center (NEREC) at Keiser.

		Height					% Head Rice					% Total Rice				
Entry	Variety	RREC	PTRS	NERREC	NEREC	Mean	RREC	PTRS	NERREC	NEREC	Mean	RREC	PTRS	NERREC	NEREC	Mean
		----------------------------(cm)--------------------------														
146	OZARK	103	105	107	101	104	47	51	59	64	55	74	67	71	72	71
121	STG19L-098	105	99	97	91	98	44	58	59	58	55	73	68	69	70	70
136	STG20L-196	109	107	105	97	105	56	53	57	63	57	73	67	69	70	70
133	STG20L-243	101	108	102	99	102	39	52	55	58	51	73	68	70	70	70
135	STG20L-264	105	106	111	104	107	43	52	54	59	52	71	68	68	69	69
130	STG19L-094	99	99	102	97	99	48	54	56	59	54	74	69	66	72	70
144	STG20L-139	104	101	103	96	101	45	57	61	61	56	73	69	71	70	71
125	STG19L-002	103	105	108	99	104	35	47	56	52	48	72	69	70	71	71
108	STG18L-106	105	104	105	98	103	34	46	51	56	47	73	70	69	71	71
140	STG20L-019	107	106	110	101	106	41	57	59	60	54	75	73	72	73	73
126	STG17L-144	107	108	107	101	106	25	44	51	57	44	72	69	69	70	70
147	Diamond	102	110	108	103	106	43	54	56	60	53	73	68	70	71	71
Entry (Pr > F)		0.00[a]	0.00[a]	0.00[a]	0.00[a]		0.00[a]	0.00[a]	0.00[a]	0.00[a]		0.00[a]	0.00[a]	0.00[a]	0.00[a]	
LSD		7.56	4.88	6.18	6.77		4.58	2.96	1.99	5.46		2.30	2.10	1.23	1.78	
% CV		5.37	3.36	4.20	4.92		7.85	4.22	2.58	6.77		2.33	2.25	1.31	1.85	

[a] Highly significant at *P*-value ≤ 0.01.

Table 3. Yield (bu./ac) and days to heading of selected of selected 10 high yielding lines and two checks in the 2022 Clearfield Long Grain Advanced Yield Trial (22 CLAYT) conducted at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC) at Stuttgart, Pine Tree Research Station at (PTRS) at Colt, Northeast Rice Research and Extension Center (NERREC) at Harrisburg, and Northeast Research and Extension Center (NEREC) at Keiser.

			Yield					Days to heading				
Entry	Variety	Pedigree	RREC	PTRS	NERREC	NEREC	Mean	RREC	PTRS	NERREC	NEREC	Mean
			----------------------(bu./ac)----------------------									
1315	20IMI-141	LAKAST/7/248DREW16C-1…	204	206	209	172	198	85	83	90	89	87
1310	RU2101177	ROYJ/CL142-AR	209	202	203	173	197	94	86	89	93	91
1301	CLL18		210	202	211	162	196	91	86	88	93	89
1307	18IMI-126	ROYJ/CL142-AR	189	205	195	183	193	90	85	91	94	90
1336	CLL16		200	195	212	161	192	94	89	91	99	93
1325	20IMI-272	TMPL/CL172	196	187	225	157	191	91	85	88	92	89
1329	19IMI-187	DREW/CL161/6/LGRU//KAT…	194	196	215	160	191	90	87	91	92	90
1323	18IMI-122	ROYJ/CL142-AR	195	199	207	164	191	93	86	88	95	91
1331	20IMI-296	DMND/3/248FRA16U-21/…	185	207	213	159	191	86	83	91	85	86
1330	20IMI-214	248DREW16C-1-3/6/LGR…	191	191	213	160	189	86	84	89	92	88
1314	20IMI-376	CL172/3/19991516/199510…	189	185	213	166	188	83	82	88	83	84
1313	RU2101216	TMPL/CL172	189	191	213	160	188	93	88	88	95	91
Entry (Pr > F)			0.00[a]	0.00[a]	0.00[a]	0.00[a]		0.00[a]	0.00[a]	0.491[b]	0.00[a]	
LSD			14.39	7.45	19.25	14.08		1.55	1.37	3.69	2.27	
% CV			5.67	2.90	7.03	6.57		1.27	1.17	3.06	1.80	

[a] Highly significant at *P*-value ≤ 0.01.

[b] Not significant.

Table 4. Height (cm), % head rice yield and % total rice of selected 10 high-yielding lines and two checks in the 2022 Clearfield Long Grain Advanced Yield Trial (22 CLAYT) conducted at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC) at Stuttgart, Pine Tree Research Station at (PTRS) at Colt, Northeast Rice Research and Extension Center (NERREC) at Harrisburg, and Northeast Research and Extension Center (NEREC) at Keiser.

		Height					-------------% Head Rice-------------					------------% Total Rice------------				
Entry	Variety	RREC	PTRS	NERREC	NEREC	Mean	RREC	PTRS	NERREC	NEREC	Mean	RREC	PTRS	NERREC	NEREC	Mean
		---------------------------(cm)-----------------------														
1315	20IMI-141	124	113	118	113	117	56	53	53	62	56	79	67	66	74	72
1310	RU2101177	116	107	112	100	109	63	54	50	60	57	77	66	63	70	69
1301	CLL18	113	109	108	99	107	59	53	50	57	55	75	66	61	70	68
1307	18IMI-126	118	111	117	113	115	58	50	48	55	53	77	66	63	68	68
1336	CLL16	120	108	116	102	112	58	53	53	62	56	74	67	66	71	70
1325	20IMI-272	131	124	129	118	125	66	63	62	65	64	77	74	69	72	73
1329	19IMI-187	113	102	108	96	105	62	58	56	61	59	75	71	67	71	71
1323	18IMI-122	112	107	112	103	109	61	60	54	62	59	77	73	65	72	72
1331	20IMI-296	119	121	122	112	118	57	55	50	58	55	75	69	64	70	70
1330	20IMI-214	121	112	120	106	115	64	60	56	62	61	75	70	66	70	70
1314	20IMI-376	120	115	115	109	115	59	57	54	60	58	75	69	66	71	70
1313	RU2101216	122	115	118	108	116	67	60	58	66	63	77	71	67	75	73
Entry (Pr > F)		0.00[a]	0.00[a]	0.00[a]	0.00[a]		0.00[a]	0.00[a]	0.00[a]	0.00[a]		0.08[b]	0.00[a]	0.00[a]	0.00[a]	
LSD		6.00	4.64	7.45	6.94		4.07	3.49	3.15	5.29		3.22	2.89	1.83	2.70	
% CV		3.87	3.14	4.82	4.91		5.03	4.58	4.29	6.43		3.10	3.05	2.04	2.77	

[a] Highly significant at P-value ≤ 0.01.

[b] Not significant.

Table 5. Yield (bu/ac) and days to heading of 11 aromatic rice lines and three checks in the 2022 Aromatic Long Grain Advanced Yield Trial (22 AROAYT) conducted at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC) at Stuttgart, Pine Tree Research Station at (PTRS) at Colt, Northeast Rice Research and Extension Center (NERREC) at Harrisburg, and Northeast Research and Extension Center (NEREC) at Keiser.

			Yield					Days to heading				
Entry	**Variety**	**Pedigree**	**RREC**	**PTRS**	**NERREC**	**NEREC**	**Mean**	**RREC**	**PTRS**	**NERREC**	**NEREC**	**Mean**
			(bu./ac)									
3708	STG20L-361	Jazzman/PI597046//Diamond	188	205	201	134	182	90	85	88	93	89
3707	STG20L-359	Jazzman/PI597046//Diamond	198	191	208	128	181	89	86	88	97	90
3706	STG20L-356	Jazzman/PI597046//Diamond	203	179	216	124	181	90	86	88	89	88
3711	STG20L-418	Jazzman/RU0701124//Diamond	190	174	206	146	179	94	90	92	96	93
3709	STG20L-358	Jazzman/PI597046//Diamond	189	194	200	132	179	89	85	88	92	89
3704	STG17L-145	Jazzman/PI597046//DELLMATI	180	203	184	149	179	96	89	94	89	92
3701	STG17L-144	Jazzman/PI597046//DELLMATI	179	200	186	138	176	96	90	93	96	94
3702	STG19L-531	JZMN/RU0701124//JZMN2/3/…	180	184	190	148	175	86	85	86	90	87
3705	STG19L-332	JZMN/RU0701124//JZMN2/3/…	184	186	199	111	170	87	86	88	89	88
3703	STG18L-413	Jazzman/PI597046//Diamond	158	191	182	149	170	91	88	88	93	90
3710	STG20L-409	JZMN/RU0701124//JZMN2/3/…	175	172	183	134	166	89	85	87	92	88
3713	Jazzman 2		140	194	172	148	163	88	85	88	94	89
3714	ARoma 22		142	175	173	151	160	87	85	88	93	88
3712	ARoma 17		150	165	170	149	159	88	87	90	95	90
Entry (Pr > F)			0.00[a]	0.26[b]	0.00[a]	0.06[b]		0.00[a]	0.00[a]	0.00[a]	0.51[b]	
LSD			12.3775	25.84	13.72	19.91		1.35	1.63	6.88	1.35	
% CV			5.07	9.94	5.17	10.31		1.12	1.31	5.33	1.08	

[a] Highly significant at *P*-value ≤ 0.01.

[b] Not significant.

Table 6. Height (cm), % head rice yield and % total rice of 11 aromatic rice lines and three checks in the 2022 Aromatic Long Grain Advanced Yield Trial (22 AROAYT) conducted at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC) at Stuttgart, Pine Tree Research Station at (PTRS) at Colt, Northeast Rice Research and Extension Center (NERREC) at Harrisburg, and Northeast Research and Extension Center (NEREC) at Keiser.

		Height					%Head Rice					%Total Rice				
Entry	Variety	RREC	PTRS	NERREC	NEREC	Mean	RREC	PTRS	NERREC	NEREC	Mean	RREC	PTRS	NERREC	NEREC	Mean
		---------------------------(cm)--------------------------														
3708	STG20L-361	105	99	102	101	102	47	40	48	61	49	69	64	68	71	68
3707	STG20L-359	104	100	103	93	100	46	44	51	58	50	69	64	69	70	68
3706	STG20L-356	108	97	104	97	101	52	47	51	59	52	70	65	68	70	68
3711	STG20L-418	102	107	111	108	107	56	55	57	59	57	68	63	67	70	67
3709	STG20L-358	104	104	105	105	104	48	46	53	57	51	70	65	69	71	68
3704	STG17L-145	115	113	120	99	112	58	57	51	67	58	75	68	70	68	70
3701	STG17L-144	112	117	119	107	114	56	56	61	51	56	74	67	70	70	70
3702	STG19L-531	112	109	111	103	109	55	56	59	51	55	76	69	71	69	71
3705	STG19L-332	119	122	125	98	116	58	61	63	60	60	73	68	70	70	70
3703	STG18L-413	99	100	102	108	102	49	46	57	54	52	74	69	71	69	71
3710	STG20L-409	116	114	112	115	114	53	46	58	57	54	71	66	70	71	70
3713	Jazzman 2	96	97	102	99	98	51	55	62	46	54	71	66	70	70	69
3714	ARoma 22	107	116	120	109	113	50	52	59	47	52	69	65	68	69	68
3712	ARoma 17	107	110	111	103	108	55	57	63	52	57	71	66	70	69	69
Entry (Pr > F)		0.00[b]	0.00[b]	0.00[b]	0.21[c]		0.00[b]	0.00[b]	0.01[b]	0.01[a]		0.00[b]	0.00[b]	0.00[b]	0.01[a]	
LSD		6.00	5.46	4.94	11.85		2.86	5.08	7.03	8.35		2.01	1.13	1.63	1.27	
% CV		4.09	3.65	3.21	8.24		3.92	7.10	8.90	10.76		2.02	1.23	1.68	1.30	

[a] Significant at *P*-value ≤ 0.05.

[b] Highly significant at *P*-value ≤ 0.01.

[c] Not significant.

Arkansas Rice Variety Advancement Trials, 2022

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Abstract

The Arkansas Rice Variety Advancement Trials (ARVAT) are conducted each year to evaluate promising experimental lines from the Arkansas rice breeding program compared to commercially available cultivars from public and private breeding programs. ARVATs are planted on experiment stations and cooperating producer's fields in a diverse range of environments, soil types, and agronomic and pest conditions. The ARVATs were conducted at 6 locations during 2022. Averaged across locations, among conventional long-grains grain yields were highest for RU2201020 at 191 bu./ac compared to the commercial checks RT XP753 (205 bu./ac), Ozark (188 bu./ac), DG263L (188 bu./ac), and Diamond (172 bu./ac). Among Clearfield long-grains grain yields were highest for 21CL1054 at 189 bu./ac, RU1801101 at 186 bu./ac, and RU2101177 at 186 bu./ac compared to the commercial checks RT 7321 FP (190 bu./ac), CLL18 (178 bu./ac), and CLL16 (173 bu./ac). Among conventional and Clearfield medium-grains, grain yields were highest for 21AR1217 at 190 bu./ac and 21AR1222 at 190 bu./ac compared to the commercial checks Taurus (181 bu./ac), Titan (161 bu./ac), and CLM04 (154 bu./ac). Among long-grain aromatics, grain yields were highest for RU2101109 at 174 bu./ac compared to the commercial check ARoma 17 (139 bu./ac). Among Provisia long-grains, grain yields were highest for 22AR2106 at 177 bu./ac compared to the commercial check PVL03 (172 bu./ac).

Introduction

Cultivar selection is likely the most important management decision made each year by rice producers. This choice is generally based upon past experience, seed availability, agronomic traits, and yield potential. When choosing a rice cultivar, grain yield, milling yield, lodging potential, maturity, disease susceptibility, seeding date, field characteristics, the potential for quality reductions due to pecky rice, and market strategy should all be considered. Data averaged over years and locations are more reliable than a single year of data for evaluating rice performance for such important factors as grain and milling yields, kernel size, maturity, lodging resistance, plant height, and disease susceptibility.

The Arkansas Rice Variety Advancement Trials (ARVAT) are conducted each year to compare promising new experimental lines from the Arkansas breeding program with established cultivars currently grown in Arkansas. Multiple locations each year allow for continued reassessment of the performance and adaptability of advanced breeding lines and commercially available cultivars to such factors as environmental conditions, soil properties, and management practices.

Procedures

The 6 locations for the 2022 ARVATs included the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC) near Stuttgart, Ark.; the Pine Tree Research Station (PTRS) near Colt, Ark.; the Northeast Research and Extension Center (NEREC) near Keiser, Ark.; the Northeast Rice Research and Extension Center (NERREC) near Harrisburg, Ark.; the Trey Bowers farm in Clay County (CLAY) near McDougal, Ark.; and the Jim Whitaker farm in Desha County (DESHA) near McGehee, Ark. Seventy-three entries, including established cultivars and promising breeding lines, were grown across a range of maturities.

The studies were seeded at CLAY, DESHA, NEREC, PTRS, RREC, and NERREC on 28 April, 20 May, 18 May, 9 May, 28 March, and 28 April, respectively. Pure-line cultivars (varieties) were drill-seeded at a rate of 33 seed/ft^2 in plots 8 rows (7.5-in. spacing) wide and 17.5-ft in length. Hybrid cultivars were drill-seeded into the same plot configuration using a seeding rate of 11 seed/ft^2. Cultural practices varied somewhat among the ARVAT locations but overall were grown under conditions for high yield.

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Nitrogen was applied to ARVAT studies located on experiment stations at the 4- to 5-leaf growth stage in a single pre-flood application of 130 lb N/ac at RREC, 145 lb N/ac at NERREC, 145 lb N/ac at PTRS, and 160 lb N/ac at NEREC using urea as the N source. The permanent flood was applied within 2 days of preflood N application and maintained throughout the growing season. Trials conducted in commercial fields (CLAY and DESHA) were managed by the grower with the rest of the field in regard to fertilization, irrigation, and weed and insect control.

Percent lodging notes were taken immediately prior to harvest. At maturity, the center four rows of each plot were harvested, the moisture content and weight of the grain were determined, and a subsample of harvested grain was removed for grain quality and milling determinations. Grain yields were adjusted to 12% moisture and reported on a bushels per acre (bu./ac) basis. The dried rice was milled to obtain percent head rice (%HR; whole kernels) and percent total white rice (%TR) presented as %HR/%TR. Each location and group of the study was arranged in a randomized complete block design with 4 replications. Statistical analysis was conducted using PROC GLM, SAS v. 9.4 (SAS Institute, Inc., Cary, N.C.) with means separation using Fisher's least significant difference test ($P = 0.10$).

Results and Discussion

Selected agronomic traits, grain yield, and milling yields for the conventional long-grain trial are shown in Table 1. Twenty-one experimental lines and 4 checks were included. The checks Ozark, DG263L, Diamond, and RT XP753 averaged 188, 188, 172, and 205 bu./ac, respectively. The experimental line RU2201020 averaged 191 bu./ac, the only variety to outperform Ozark and DG263L.

Selected agronomic traits, grain yield, and milling yields for the Clearfield long-grain trial are shown in Table 2. Twenty-two experimental lines and 3 checks were included. The checks CLL16, CLL18, and RT 7321 FP averaged 173, 178, and 190 bu./ac, respectively. The experimental lines 21CL1054 (189 bu./ac), RU1801101 (186 bu./ac), RU2101177 (186 bu./ac), 21AR1117 (184 bu./ac), 21CL628 (183 bu./ac), RU2101101 (181 bu./ac), and several other entries performed higher than the CLL16 and CLL18 checks.

Selected agronomic traits, grain yield, and milling yields for the conventional and Clearfield medium-grain trials are shown in Table 3. Eight experimental lines and 3 checks were included. The checks Titan, CLM04, and Taurus averaged 161, 154, and 181 bu./ac, respectively. The Clearfield experimental lines 21AR1217 (190 bu./ac), 21AR1222 (190 bu./ac), RU2101234 (188 bu./ac), and the conventional experimental line RU1901165 (185 bu./ac) performed higher than all checks.

Selected agronomic traits, grain yield, and milling yields for the conventional and Clearfield long-grain aromatic trials are shown in Table 4. Five experimental lines and 1 check were included. The check ARoma 17 averaged 139 bu./ac. All experimental lines performed higher than the check, with RU2101109 (174 bu./ac), 21AR2909 (173 bu./ac), and 21AR2931 (172 bu./ac) having the highest yields.

Selected agronomic traits, grain yield, and milling yields for the Provisia long-grain trial are shown in Table 5. Five experimental lines and 1 check were included. The check PVL03 averaged 172 bu./ac. The experimental line 22AR2106 had the highest yield of 177 bu./ac and 4 of the 5 other lines also outperformed the PVL03 check.

Practical Applications

Data from this study will assist the rice breeding program with variety advancement and release decisions to provide rice producers with new cultivars suitable to the wide range of growing conditions found throughout Arkansas.

Acknowledgments

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Table 1. Grain yield and agronomic traits of conventional long-grain experimental lines and commercial checks in the Arkansas Rice Variety Advancement Trials (ARVAT) by location in 2022.

Entry	Grain Type[a]	50% Heading	Plant Height	Lodging	Milling Yield	Clay[b]	Desha	NEREC	PTRS	RREC	NERREC	Mean
		(days)	(in.)	(%)	(%HR/%TR)	-----------	-----------	-----------	(bu./ac)	-----------	-----------	-----------
RU2201020	L	88	39	4	59/71	172	179	203	197	201	189	191
21AR133	L	89	40	2	61/70	164	175	195	194	196	184	185
21AR136	L	91	39	2	62/70	170	158	193	193	203	193	187
RU2001125	L	88	42	0	60/70	170	183	197	188	190	192	186
21AR148	L	92	40	0	59/70	131	172	176	178	178	183	171
21AR172	L	92	44	0	58/71	139	171	185	179	193	175	173
22AR181	L	89	41	0	58/71	162	183	190	190	189	195	184
22AR182	L	87	41	7	55/70	167	193	188	173	186	195	183
21AR166	L	89	41	0	57/71	172	181	188	173	193	181	181
22AR183	L	89	38	1	56/70	173	158	197	183	195	189	184
21HX113	LH	85	38	7	48/69	183	160	172	205	189	177	182
21HX023	LH	86	45	13	50/70	175	153	145	120	167	150	151
21HX111	LH	81	38	20	44/68	172	179	165	152	158	170	165
RU2101201	L	91	43	0	59/70	149	189	175	188	190	184	180
21LG352	L	92	41	0	58/69	161	164	169	188	171	182	173
21LG1970	l	89	40	0	59/70	174	154	195	192	191	191	184
21LG1931	L	92	41	0	60/71	174	167	185	200	176	166	178
21LG1980	L	92	41	3	61/70	143	157	186	185	180	176	171
21LG1981	L	92	41	0	55/69	151	164	189	184	185	163	173
21LG2065	L	89	40	0	61/71	152	144	170	181	178	158	164
21LG2056	L	92	41	5	60/71	136	149	166	188	165	167	162
Ozark	L	88	39	0	61/71	182	169	198	198	197	189	188
DG263L	L	86	36	25	53/69	200	167	164	215	189	189	188
Diamond	L	88	40	0	58/70	164	177	174	182	174	161	172
RT XP753	LH	86	42	7	53/71	215	174	223	187	208	220	205
$LSD_{(0.10)}$[c]		2	1	5	1.8/0.4	31	19	17	15	13	10	8

[a] Grain type: L = conventional long-grain, LH = long-grain hybrid, long-grain.

[b] Clay = Clay Co., McDougal, Ark.; Desha = Desha Co., McGehee, Ark.; NEREC = Northeast Research and Extension Center, Keiser, Ark.; PTRS = Pine Tree Research Station, Colt, Ark.; RREC = Rice Research and Extension Center, Stuttgart, Ark.; and NERREC = Northeast Rice Research and Extension Center, Harrisburg, Ark.

[c] LSD = least significant difference.

Table 2. Grain yield and agronomic traits of Clearfield long-grain experimental lines and commercial checks in the Arkansas Rice Variety Advancement Trials (ARVAT) by location in 2022.

Entry	Grain Type[a]	50% Heading	Plant Height	Lodging	Milling Yield	Clay[b]	Desha	NEREC	PTRS	RREC	NERREC	Mean
		(days)	(in.)	(%)	(%HR/%TR)	(bu./ac)						
RU2201019	CL	90	39	0	61/71	183	183	173	169	181	178	177
RU1801101	CL	92	38	0	63/71	185	193	171	194	196	180	186
21AR1121	CL	91	34	1	60/70	174	164	171	183	180	175	175
RU2101101	CL	87	38	3	60/69	190	176	177	189	186	166	181
21HX120CL	CLH	87	45	25	54/70	185	127	181	152	184	163	165
21AR1117	CL	86	36	0	61/72	189	185	164	181	201	181	184
RU2001121	CL	89	39	0	63/72	183	184	164	178	181	162	175
21AR1115	CL	87	36	0	60/70	196	170	181	193	172	169	180
21AR1124	CL	92	39	0	62/71	185	176	166	188	179	174	178
RU2101177	CL	92	41	0	59/69	184	185	186	193	190	176	186
21CL1018	CL	93	41	0	63/71	159	150	166	166	175	155	162
21CL628	CL	90	43	0	58/70	190	192	182	187	187	164	183
21CL607	CL	94	42	0	59/71	169	180	173	162	184	167	172
21CL911	CL	90	38	0	51/71	186	179	179	179	179	171	179
21CL1076	CL	89	42	0	58/70	181	184	173	181	184	165	178
21CL948	CL	89	41	0	59/70	165	169	181	174	185	172	174
21CL916	CL	90	40	1	62/72	192	168	185	192	182	165	180
21CL1006	CL	95	42	0	65/71	151	154	164	171	175	153	161
21CL918	CL	92	42	1	59/71	177	172	187	180	183	160	177
21CL1054	CL	90	37	0	64/72	191	170	181	194	204	192	189
21CL1024	CL	92	40	0	62/71	166	143	179	175	194	174	173
21CL958	CL	91	43	0	60/72	171	170	182	182	173	155	172
RT 7321 FP	FLH	94	43	15	50/71	218	154	183	170	212	196	190
CLL18	CL	91	41	1	60/70	175	171	182	191	183	169	178
CLL16	CL	92	40	0	58/69	172	161	181	180	185	162	173
$LSD_{(0.10)}$[c]		1	1	2	1.5/0.6	20	18	NS	11	9	8	6

[a] Grain type: CL = Clearfield long-grain, FLH = FullPage long-grain hybrid, CLH = Clearfield long-grain hybrid.

[b] Clay = Clay Co., McDougal, Ark.; Desha = Desha Co., McGehee, Ark.; NEREC = Northeast Research and Extension Center, Keiser, Ark.; PTRS = Pine Tree Research Station, Colt, Ark.; RREC = Rice Research and Extension Center, Stuttgart, Ark.; and NERREC = Northeast Rice Research and Extension Center, Harrisburg, Ark.

[c] LSD = least significant difference.

Table 3. Grain yield and agronomic traits of conventional and Clearfield medium-grain experimental lines and commercial checks in the Arkansas Rice Variety Advancement Trials (ARVAT) by location in 2022.

Entry	Grain Type[a]	50% Heading	Plant Height	Lodging	Milling Yield	Clay[b]	Desha	NEREC	PTRS	RREC	NERREC	Mean
		(days)	(in.)	(%)	(%HR/%TR)	----------	----------	----------	(bu./ac)	----------	----------	----------
RU2101113	M	89	37	0	54/70	184	168	199	150	189	180	178
RU2201044	CM	86	37	0	59/70	188	164	180	139	186	175	172
21AR1217	CM	91	36	0	58/70	218	192	193	142	194	204	190
RU2101234	CM	91	37	0	57/69	204	174	196	167	194	191	188
RU1901165	M	89	35	0	61/70	194	168	199	156	194	192	185
RU1901137	CM	93	37	0	58/70	192	186	181	142	181	188	178
RU1801238	CM	89	38	0	56/70	188	175	187	150	183	166	175
21AR1222	CM	88	35	0	52/70	209	179	207	154	190	201	190
Titan	M	85	37	0	54/70	180	165	164	116	176	168	161
CLM04	CM	89	40	12	61/70	167	163	123	145	169	160	154
Taurus	M	85	35	6	55/70	190	182	164	146	201	201	181
$LSD_{(0.10)}$[c]		1	1	3	1.6/0.5	11	21	18	11	8	11	7

[a] Grain type: CM = Clearfield medium-grain, M = conventional medium-grain.

[b] Clay = Clay Co., McDougal, Ark.; Desha = Desha Co., McGehee, Ark.; NEREC = Northeast Research and Extension Center, Keiser, Ark.; PTRS = Pine Tree Research Station, Colt, Ark.; RREC = Rice Research and Extension Center, Stuttgart, Ark.; and NERREC = Northeast Rice Research and Extension Center, Harrisburg, Ark.

[c] LSD = least significant difference.

Table 4. Grain yield and agronomic traits of conventional and Clearfield long-grain aromatic experimental lines and commercial checks in the Arkansas Rice Variety Advancement Trials (ARVAT) by location in 2022.

Entry	Grain Type[a]	50% Heading	Plant Height	Lodging	Milling Yield	Clay[b]	Desha	NEREC	PTRS	RREC	NERREC	Mean
		(days)	(in.)	(%)	(%HR/%TR)	(bu./ac)						
RU2101208	CLA	95	38	3	59/69	--	--	171	183	160	161	169
RU2101109	LA	93	44	2	62/70	--	--	171	167	188	172	174
RU2201046	LA	97	43	0	58/70	--	--	168	167	171	172	169
21AR2931	LA	97	43	0	58/70	--	--	176	166	180	167	172
21AR2909	LA	93	45	0	60/70	--	--	188	168	164	174	173
ARoma17	LA	93	40	0	58/70	--	--	140	126	139	150	139
$LSD_{(0.10)}$[c]		1	1	NS	2.6/0.5	--	--	11	11	15	10	7

[a] Grain type: LA = long-grain aromatic, and CLA = Clearfield long-grain aromatic.

[b] Clay = Clay Co., McDougal, Ark.; Desha = Desha Co., McGehee, Ark.; NEREC = Northeast Research and Extension Center, Keiser, Ark.; PTRS = Pine Tree Research Station, Colt, Ark.; RREC = Rice Research and Extension Center, Stuttgart, Ark.; and NERREC = Northeast Rice Research and Extension Center, Harrisburg, Ark.

[c] LSD = least significant difference.

Table 5. Grain yield and agronomic traits of Provisia long-grain experimental lines and commercial checks in the Arkansas Rice Variety Advancement Trials (ARVAT) by location in 2022.

Entry	Grain Type[a]	50% Heading	Plant Height	Lodging	Milling Yield	Clay[b]	Desha	NEREC	PTRS	RREC	NERREC	Mean
		(days)	(in.)	(%)	(%HR/%TR)	(bu./ac)						
22AR2103	PL	93	39	0	60/70	178	196	184	176	168	151	175
22AR2105	PL	89	37	1	60/70	178	165	167	170	163	160	167
22AR2106	PL	89	37	0	59/70	182	160	177	183	177	182	177
RU2201021	PL	90	38	0	63/71	166	187	177	185	182	156	175
22AR2115	PL	90	37	0	61/71	161	185	181	172	177	170	174
PVL03	PL	88	38	0	60/71	186	172	156	168	183	166	172
$LSD_{(0.10)}$[c]		1	1	NS	1.5/0.5	NS	14	7	9	NS	10	5

[a] Grain type: PL = Provisia long-grain.

[b] Clay = Clay Co., McDougal, Ark.; Desha = Desha Co., McGehee, Ark.; NEREC = Northeast Research and Extension Center, Keiser, Ark.; PTRS = Pine Tree Research Station, Colt, Ark.; RREC = Rice Research and Extension Center, Stuttgart, Ark.; and NERREC = Northeast Rice Research and Extension Center, Harrisburg, Ark.

[c] LSD = least significant difference.

University of Arkansas System Division of Agriculture Hybrid Rice Breeding Progress in 2022

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Abstract

Efforts in 2022 were made by the University of Arkansas System Division of Agriculture's (UADA) Rice and Research Extension Center's (RREC) hybrid rice breeding program in developing hybrid rice (*Oryza sativa* L.) varieties; which include developing environmentally sensitive male sterile (EGMS) lines, cytoplasmic male sterile (A) lines, maintainer (B) lines, and restorer (R) lines. As parental line development was being attempted, test crosses were also made to evaluate both parents and the experimental hybrids. Parents were planted as panicle rows to select based on phenotypes, while simultaneously being crossed with other parental lines to produce test crosses to be evaluated in 2023. Efforts for hybrid variety development with Provisia® and Clearfield® herbicide technologies were also attempted. Lastly, successful hybrid seed (F_1) production of 13 hybrid combinations was achieved, which enables us to test these new hybrids in the Advanced Elite Line Yield Trials (AYT) and/or Arkansas Rice Variety Advancement Trials (ARVAT) across the state in 2023.

Introduction

A hybrid rice breeding program requires a multiple pipeline scheme compared to a more straightforward conventional rice breeding approach. This scheme is required due to the need of multi-parental line development and a male sterility system for the production of hybrid seed. Hybrid seed is first-generation (F_1) only, thus when grown, the selfed seed (F_2) produced by the hybrid plants will not perform the same if grown due to segregating genes affecting traits among the plants (Virmani et al., 1997). There is also an added level of difficulty because the required genes for incorporating both male sterility and fertility restoration are found in *Indica* type rice varieties (Virmani et al., 1997), which are not suitable for growing in the Arkansas climate where *Tropical japonica* type rice is grown. On top of that, most of these lines are not accessible due to the protection of intellectual property. These unique male sterility genes were originally found in rice fields that experienced spontaneous mutations, while some were created by making wide crosses among genetically diverse rice varieties (Li et al., 2007).

Hybrid seed can be produced by using either a 2-line or a 3-line method. The names of the methods are the required number of parents needed for hybrid seed production, but the same is true for both methods: a male sterile parent is needed that serves as the female parent. For the 2-line method the sterility of a female parent is induced by environmental conditions such as high daily temperatures, long daylengths, or a combination of both; and it can be self-fertilized at lower daily temperatures, shorter daylengths, or a combination of both (Virmani et al., 2003). The pollen parent can be any rice variety, but additional flowering traits such as good anther dehiscence, good anther protrusion, large anther size, and high pollen load are needed for successful hybrid rice production, which may not be prevalent in all rice varieties. For the 3-line method the female parent (A line) is male sterile due to a genetic interaction between cytoplasm and nucleus in which its seed can only be re-produced when crossing with its genetically similar maintainer line (B line). The B line serves as the male parent for the propagation of the female parent (A line). The third line (R line) requires specific restorer gene(s) that serves as the male parent for hybrid seed production (Virmani et al., 1997).

Because the magnitude of the objectives involved in handling both methods is too great, most international hybrid rice breeding programs divide the two methods into separate breeding programs, sometimes even having multiple projects within the already divided programs. Both methods are required, however, to completely approach all the possibilities for developing a hybrid rice variety. This results in the need to develop five parental lines (S, A, B, and R lines, and pollen parents). Even after developing the parents, thousands of testcrosses must be made among the parents, the resulting testcrosses must be evaluated, and the best testcrosses must be re-produced annually and further tested until a hybrid variety is identified. With the revamp of the UADA hybrid rice breeding program initiated in 2021 (North et al., 2021), the program has been focused on accomplishing these objectives.

Procedures

2-Line Method

The 2-line method of hybrid rice production requires S line development, pollen parent selection, testcrossing, testcross evaluation, hybrid seed production, and advanced hybrid testing. S line development consisted of 22 advanced lines derived from the UADA hybrid rice breeding program's TGMS lines (North et al., 2019). These lines were evaluated based on combining ability and flowering characteristics used for testcrossing. Six of those lines were planted as head rows to evaluate their sterility and uniformity. All 22 of the S-lines were used for testcrossing, while 6 were used for large hybrid seed production. An additional step for the selection and purification of the S-lines was added in 2022.

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Marker-assisted selection (MAS) has become more accessible to the breeding program and allows the breeder to select for qualitative traits such as disease resistance, amylose content, chalkiness, aroma, leaf pubescence, and herbicide resistance (if present).

S lines development with Provisia® technology was initiated in 2019. In 2022 6 F_2 populations, and 41 F_4 lines were planted as panicle rows (5 ft length and 10 in row spacing) and selected based on sterility, desirable phenotypes, and Provisia® herbicide tolerance. Selected plants were later dug up, placed into pots, treated with cooler temperatures, and placed inside a greenhouse for seed production in late fall.

Testcrossing is similar to pure-line crossing in which the female panicle is prepared by snipping spikelets (without the need for emasculation) and male panicles are collected to pollinate the female panicles. For larger hybrid seed production planting was done using three methods: 1) 3 passes (130 ft length) of a male parent (7-rows, 8 in spacing) and 2 passes of 2 different S-lines within a block 44 ft wide to allow for 2 hybrid combinations; 2) 2 passes of a male parent (same planting dimensions) and 1 pass of a S-line within a block 32 ft wide; and 3) 4 rows of 7 S-lines (10 in spacing, 10 ft length/S-line) planted in-between 20 rows of a male parent. Corn was planted on the levees and outside of the blocks for methods 1 and 2 to serve as pollen barriers of alternating male parents used and nearby rice fields to improve hybrid seed purity.

Testcrosses made in 2021 or before, were evaluated in two ways: 1) preliminary yield trial (SIT) that consisted of 33 hybrids that were planted 7 rows wide with 8 in spacing and 15 ft length, with 2 replications; 2) observation trial (OBT) consisting of 259 testcrosses (69 with Clearfield® trait) planted as rows with 10 in row spacing and 5 ft length. Method 1 results concluded with combine harvesting of selected hybrid plots that displayed uniformity, and method 2 concluded with the evaluation of hybrid rows based on plant uniformity, desirable phenotypes, maturity, hand-harvest of best-looking testcrosses, and milling quality evaluation.

Advanced hybrids were tested in three trials: 1) Advanced yield trial (AYT) that consisted of 9 hybrids that were planted 7 rows wide with 8 in spacing and 15 ft length, with 3 replications at 3 locations; 2) the Clearfield® advanced yield trial (CAYT) that consisted of 3 hybrids that were planted like the AYT test, except at only 2 locations; and 3) the Arkansas rice variety advancement trial (ARVAT) which included 4 hybrids that were planted 8 rows wide with 7.5 in spacing and 18 ft length, with 4 replications at 6 locations.

3-Line Method

The 3-line method of hybrid rice production requires A, B, and R line development; testcrossing; testcross evaluation; hybrid seed production; and advanced hybrid testing. The hybrid rice breeding program started A, B line development previously with lines accessible through the USDA world collection. Marker-assisted selection was also initiated for the program in 2022 for additional screening of the lines for selections of qualitative traits.

Seven hundred forty-seven B lines ranging from F_3 to F_7 generations were planted as panicle rows and selected based on desirable phenotypes. Testcrosses were made with A lines and the progeny must be evaluated in the 2023 season to determine complete sterility for the development of new A lines.

There were 3,285 R lines spanning F_3 to F_6 generations that were planted as panicle rows and selected based on desirable phenotypes. Testcrosses were made with A and S lines to evaluate the progeny in the 2023 season to determine the combining ability of the R line and the heterosis performance. Three advanced R-lines (1 with Clearfield® technology) were used to cross with A and S-lines for hybrid seed production.

Eighteen R lines were tested in a preliminary yield trial (SIT) that were planted 7 rows wide with 8 in spacing and 15-ft length, with 2 replications. Good yields and desirable phenotypes of advanced R lines can increase the chance of a high-yielding hybrid, or even a R line can be released as a pure-line variety.

Testcrossing for 3-line hybrids is similar to pure-line crossing as described previously. The layout of the hybrid seed production is the same as described for the 2-line hybrid seed production method 1.

Three-line testcrosses made in 2021 were evaluated via OBT consisting of 56 testcrosses planted as rows with 10-in. row spacing and 5-ft length. The testcrosses were phenotyped for maturity, height, uniformity, row weight, milling, and grain appearance. One experimental 3-line hybrid was tested in the AYT in 2022.

Results and Discussion

2-Line Method

For S-line development and purification 18 of the 22 lines were selected in which 360 plants were harvested from those after being temperature treated in the cool shed, and finished maturing in the greenhouse. Upon the results of the MAS data, some of the plants will be discarded if any of the traits are still segregating or undesirable. The seeds were sent to the Puerto Rico winter nursery as head rows to be further purified and harvested in spring 2023.

For the Provisia® S line development 42 F_2 populations, 161 F_3 lines, and 68 F_5 lines were selected, temperature treated in the cool shed, and harvested in the greenhouse. From these selected lines additional selection will occur based on MAS results collected from the plants' leaves. The final selected lines will be grown in 2023 as panicle rows, and some of the F_5-F_6 lines will be testcrossed with male parents to test Provisia® hybrids.

The program continues to grow and move forward producing 330 testcrosses (201 conventional, 110 Clearfield®, and 19 Provisia®) and 12 (8 conventional, 3 Clearfield®, and 1 Provisia®) experimental hybrids in 2022. This is the largest amount in the program's history. The 9 most promising experimental hybrids will be tested in the 2023 Arkansas Rice Variety Advancement Trials (ARVAT), 8 in the Advanced Elite Line Yield Trial (AYT), 3 in the Clearfield® AYT (CAYT), and one Provisia® (PVL) hybrid in the Provisia® advanced yield trial (PAYT). The 201 conventional long-grain testcrosses will be tested in the 2023 OBT, and 110 CL testcrosses will be tested in the CL OBT, and the 19 PVL testcrosses will be tested in the PVL OBT to evaluate for desirable phenotypes, maturity, seed setting, yield potential, milling, and grain and cooking quality.

Of the 259 testcrosses evaluated in the 2022 OBT, 40 were harvested based on desirable phenotypes. The seed from the selections will be used to check milling quality. Upon these results if any are selected then hybrid seed production of these combinations will be made in 2023. There were no hybrids that outperformed the hybrid check 'RT7321FP' (250 bu./ac) in the 2022 SIT, however, 5 performed better that the conventional checks 'Ozark' (207 bu./ac) and 'CLL16' (206 bu./ac).

The results from the 2022 AYT revealed 3 experimental hybrids yielding (227, 229, and 257 bu/A) higher than the pure-line checks: 'DG263L' (209 bu./ac), 'Diamond' (196 bu./ac), and 'Ozark' (216 bu./ac). The highest yielding experimental hybrid compared closely to the hybrid check 'RT XP753' (266 bu./ac). Unfortunately, this experimental hybrid has a plant height at 60 in. compared to 'RT XP753' height of 47 in. Attempts will be made to reduce the height.

The 2022 CAYT results revealed that 1 of the 3 experimental hybrids had closer yields (252 bu./ac) compared to the hybrid check 'RT7321FP' (263 bu./ac). Fortunately, the height is similar to the experimental hybrid measuring at 52 in. compared to the check at 48 in.

Last of the yield trial results concludes with the 2022 ARVAT. The 4 experimental hybrids did not show any yield potential in this trial. The purpose for having all of these yield trials is to verify the experimental hybrid performance and what does great in some trials and what performs poorly in others. The variability of environments and management practices will reduce the risk of releasing a poor-performing hybrid that would hurt both the Arkansas rice growers and the reputation of the UADA breeding program. At all costs, the program will avoid this.

3-Line Method

For B-line development, there were 1,150 panicles harvested from 26 F_2 populations to be grown as panicle rows in 2023. Five panicles were harvested from 235 panicle rows, and 48 of those selected rows were bulk harvested to evaluate milling quality. The harvested panicles will be planted in 2023 for line advancement and further selection. Additional backcrosses and testcrosses are planned for A line development.

Of the 18 advanced R lines tested in the 2022 SIT only 1 performed well (193 bu./ac) as compared with DG263L (184 bu./ac). There were 4,075 panicles harvested from 124 F_2 populations to be grown as panicle rows in 2023. Five panicles were harvested from 525 panicle rows, and 22 of the selected rows were bulk harvested to test in the 2023 SIT. The harvested panicles will be planted in 2023 for line advancement, further phenotyping, and testcrossing with female lines for evaluating combining ability in 2023.

There were 179 (168 conventional, and 11 Clearfield®) testcrosses produced in 2022. The 168 conventional long-grain testcrosses will be tested in the 2023 OBT, and 11 CL testcrosses will be tested in the CL OBT. One new, experimental hybrid was produced with CL technology and will be tested in the 2023 CAYT.

In the OBT trial, 6 of the 56 testcrosses were selected based on desirable phenotypes. The seed from the selections will be used to check milling quality. Upon these results if any are selected then hybrid seed production of these combinations will be made in 2023. The one, experimental hybrid in the 2022 AYT performed fair (187 bu./ac), but still inferior to commercial hybrid checks.

Practical Applications

At harvesting time for the 18 S lines in Puerto Rico in Spring 2023 the program will decide which ones to select as the prominent females to be crossed with many male (pollen parents) in Summer 2023 for 2-line hybrid seed production. Efforts are being made for developing S lines with Provisia® technology that will later be used for the development of Provisia® hybrid varieties. There were 330 (2-line) test crosses made that will be evaluated in 2023 which is the most made in the program's history. The OBT and yield trial results reveal that some experimental hybrids have potential, but are not quite at commercial hybrid standards. The greater number of testcrosses made in 2022 will help lead to the right combinations to produce a commercial-scale hybrid as it appears the yield potential is present in the program's germplasm. Multiple B and R lines are in development and being simultaneously used to cross with the A lines to check maintainer and restorer ability while evaluating their agronomic characteristics, grain quality, and yield potential. With 179 (3-line) testcrosses made (again, the most made in the program's history) there will be an ample amount to evaluate in 2023 to lead to the right combination for high- yielding hybrids. Sufficient amounts of hybrid seeds were produced in 2023, which enables us to have 13 new experimental hybrids. Of the 13, 8 are conventional, 4 are Clearfield® (one of which is a 3-line), and 1 is Provisia® (first-ever UADA PRV experimental hybrid). The 8 conventional will be evaluated in the 2023 AYT, the 4 CL will be evaluated in the 2023 CAYT, and the 1 PRV will be evaluated in the 2023 PAYT. Nine of the 13 will also be simultaneously tested in the 2023 ARVAT.

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Evaluation of Advanced Medium-Grain and Long-Grain Breeding Lines at Three Arkansas Locations

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Abstract

For rice breeders to identify the ideal breeding lines for potential varietal releases it is critical to have a yield trial under the most representative soil types and environmental conditions. To bridge the gap between the single location, 2–3 replication preliminary yield trials with over 1,400 breeding lines and the multi-state Cooperative Uniform Regional Rice Nursery (URRN) and/or the multi-location statewide Arkansas Rice Variety Advancement Trials (ARVAT), which only accommodate a very limited number of entries, an advanced elite line yield trial (AYT) was initiated in 2015. The trial is conducted at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC), near Stuttgart, Ark.; the University of Arkansas System Division of Agriculture's Pine Tree Research Station (PTRS), near Colt, Ark.; and the University of Arkansas System Division of Agriculture's Northeast Research and Extension Center (NEREC), in Keiser, Ark. This trial will help us to select the best and the most uniform breeding lines for advancement into the URRN and/or ARVAT trials, and ultimately will improve the quality of those yield trials.

Introduction

Complex traits, such as yield and quality can only be evaluated effectively in replicated yield trials. Once reaching a reasonable uniformity, rice breeding lines are bulk-harvested and tested in the single location, 2–3 replication preliminary yield trials, which include the Clearfield® (CL) Stuttgart Initial Trial (CSIT), Provisia® (PV) Stuttgart Initial Trial (PSIT) or Conventional Stuttgart Initial Trial (SIT). Each year, about 1,400 new breeding lines are tested in CSIT, PSIT, or SIT trials. About 10% of the tested breeding lines, which are expected to yield statistically or numerically higher than commercial checks and possess desirable agronomical characteristics, need to be tested in replicated and multi-location advanced yield trials. However, the current advanced yield trials including the multi-state Uniform Regional Rice Nursery (URRN) and statewide ARVAT only can accommodate about 35 entries from each of the three rice breeding projects each year. Obviously, a new replicated and multi-location trial is needed to accommodate those additional breeding lines. In addition to the verification of the findings in the previous preliminary trials, the new trial will result in purer and more uniform seed stock for URRN and ARVAT trials.

Procedures

A total of 80 entries were tested in 2022 AYT trial, which included 58 experimental long-grain and 6 medium-grain lines, 10 experimental hybrids, and 6 commercial check varieties. Nine of the experimental lines were also concurrently tested in 2022 URRN and/or ARVAT trials. As companion tests, a 30-entry CL AYT (CAYT) and a 20-entry PV AYT (PAYT) were also carried out and a 2X recommended rate of NewPath and Provisia herbicides were applied, respectively. The CAYT included 16 experimental CL long-grain and 7 CL medium-grain lines, 3 CL experimental hybrids, and 4 commercial checks, while the PAYT was made up of 18 PV long-grain lines and 2 commercial checks. The experimental design is a randomized complete block with three replications. Plots measuring 4.38 feet wide (7 rows with a 7.5-in. row spacing) and 14.25 feet long were drill-seeded at 85 lb/ac rate. All seeds were treated with AV-1011 (18.3 fl oz/cwt) and CruiserMaxx Rice (7 fl oz/cwt) for blackbird and insect pests. The soil types at the NEREC, the PTRS, and the RREC are Sharkey clay, Calloway silt loam, and DeWitt silt loam, respectively. Trials at NEREC were planted on 13 May, PTRS on 9 May, and RREC on 4 April (CAYT RB1 and PAYT RB1), 11 April (AYT RB1), 28 April (CAYT RB2 and PAYT RB2), and 16 May (AYT RB2). A single pre-flood application of 129 lb/ac (160 lb/ac at NEREC) nitrogen in the form of urea was applied to a dry soil surface at the 4- to 5-leaf stage, and a permanent flood was established 1–2 days later. At maturity, all trials were harvested by using a Wintersteiger Quantum plot combine (Wintersteiger AG, 4910 Ried, Austria), and the moisture content and plot weight were determined by the automated weighing system HarvestMaster that is integrated into the combine. A small sample of seed was collected of the combine from each plot for later milling yields determination. Milling evaluations were conducted in house on a Zaccaria PAZ-100 sample mill (Zaccaria, Limeira, Brazil). Grain yields were calculated as bushel per acre and adjusted for 12% moisture content.

Data were analyzed using the General Linear Model procedure of SAS software, v. 9.4 (SAS Institute, Cary, N.C.). A combined

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analysis of variance across all locations was performed for grain yield, milling yields, days to 50% heading, plant height, and seedling vigor. The means were separated by Fisher's protected least significance difference (LSD) test at the 0.05 probability level.

Results and Discussion

The average AYT grain yield of all entries across 3 locations and 4 planting dates is 198 bu./ac (Table 1), which is lower than the 232 and 220 bu./ac averages in 2021 and 2020, respectively. The first planting at RREC has the highest average yield of 221 bu./ac and is followed by 207 and 196 bu./ac of PTRS and the second planting at RREC, respectively. Delayed planting due to wet weather in early spring most likely contributed to the lower-than-normal average yield especially at NEREC. Similar to that reported in commercial production fields, the average grain yield of medium-grain entries is only 179 bu./ac, which is 21 bu./ac lower than long-grain entries. The top 6 highest-yielding entries are commercial hybrids 22AYT03 (RT XP753), experimental hybrids 22AYT18 (21HX024), 22AYT17 (21HX023), and 22AYT13 (21HX18), followed by experimental long-grain line 22AYT59 (22AR159) with the average grain yield of 266, 257, 229, 227, and 218 bu/A, respectively. The average milled head rice and total rice yield across locations are 63% and 68%, respectively, which are higher than 60% and 67% of 2021 but lower than 66% and 71% of 2020.

The five highest-yielding conventional medium-grain entries are 22AYT08 (new release Taurus), 22AYT06 (Lynx), 22AYT42 (22AR242), 22AYT41 (22AR241), and 22AYT43 (22AR343) with the average yield of 203, 201, 195, 190, and 167 bu./ac, respectively. Of 60 conventional experimental long-grain lines, 36 out-yielded Diamond, 8 outperformed DG263L, and 2 even had a slight yield advantage over newly released Ozark. Among the top performing lines, 22AYT59, 22AYT49, 22AYT47, 22AYT26 (RU2201020), 22AYT51, and 22AYT22 (21AR136) have an average yield of 218, 217, 216, 215, and 214 bu./ac, as compared with 196, 209, and 216 of Dimond, DG263L, and Ozark, respectively. Most of these top-yielding experimental lines will be advanced or re-tested in the 2023 ARVAT and/or URRN trials.

The average grain yield of CAYT across locations/planting dates is 204 bu./ac (Table 2), which is 10 bu./ac lower than that of 2021. The PTRS site has the highest grain yield of 205.8 bu./ac, closely followed by 205.6 and 200.5 bu./ac of the second and the first planting at RREC, respectively. The average milling yields are 62% head rice and 68% total rice, which are higher than 59% and 66% of 2021. RiceTec FullPage® hybrid RT 7321 FP (22CAYT04) had the highest yield of 263 bu./ac, followed by experimental CL hybrids 22CAYT05 (21HX120CL) and 22CAYT07 (21HX123CL), CL medium-grain 22CAYT09 (21AR1217), and 22CAYT02 (newly released CLL18) with an average yield of 252, 229, 229, and 223 bu./ac, respectively. Among CL long-grain entries, CLL18 had the highest yield of 223 bu./ac, however 3 lines outperformed the predominant check CLL16. The top 5 lines are 22CAYT21, 22CAYT22, 22CAYT23, 22CAYT11 (RU2101221), and 22CAYT29 with an average yield of 220, 212, 210, 206, and 205, respectively, as compared with 209 bu./ac of CLL16. The CL medium-grain lines had slightly lower yield than CL long-grains. The top-performing CL medium-grain lines include 22CAYT09 (21AYT1217), 22CAYT26, 22CAYT28, 22CAYT17, and 22CAYT27 with an average yield of 229, 211, 202, 197, and 197 bu./ac, respectively, as compared with the 189 bu./ac of CLM04.

Our Provisia rice breeding program was launched in February 2019. Through extensive crossing/backcrossing, rapid generation advancement, and intensive selection and re-selection, a number of PV long-grain lines were developed in a very short time and tested in our new PAYT trial (Table 3). The average grain yield is 190 bu./ac, and the average milling yields are 63% head rice and 68% total rice, as compared with 183 bu./ac, 55%, and 65% of 2021, respectively. The second planting at RREC had the highest average yield of 201 bu./ac, followed by 199, 170, and 168 bu./ac of PTRS, the first planting of RREC, and NEREC, respectively. All 18 experimental lines yielded significantly ($P < 0.05$) higher than check PVL02, while 10 of the 18 outperformed the new PVL03. 22PAYT07 (RU2201021), 22PAYT11, 22PAYT06, 22PAYT03, and 22PAYT12 are the top-performing lines with an average grain yield of 206, 199, 199, 198, and 198 bu./ac, as compared with 162 and 192 bu./ac of checks PVL02 and PVL03, respectively. A 6.5 acreage breeder seed increase of RU2201021 is currently grown in Puerto Rico winter nursery for potentially fast-tracked commercial launch in 2024.

Practical Applications

The new AYT trials successfully bridged the gap between the single location preliminary yield trials with numerous entries and the multi-state or statewide advanced yield trial that can only accommodate a minimal number of entries, and provided opportunities for the trial of additional elite breeding lines. Our results enable us to confirm the findings from other yield trials, and identify the outstanding breeding lines, which were excluded from URRN or ARVAT trials due to insufficient slots.

Acknowledgments

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Table 1. Grain and milling yields of 80 long- and medium-grain breeding lines and commercial checks in the advanced elite line yield trial (AYT) conducted at the University of Arkansas System Division of Agriculture's Northeast Research and Extension Center (NE) at Keiser, Pine Tree Research Station (PT) near Colt, and Rice Research and Extension Center (RB) near Stuttgart, 2022.

			Grain Yield					%HR/
Entry	Pedigree	GT[a]	NE	PT	RB1[b]	RB2[b]	Mean	%TR[c]
			-----------------(bu./ac)-----------------					
22AYT01	Diamond	L	178	191	216	199	196	63/68
22AYT02	DG263L	L	219	213	213	196	209	63/67
22AYT03	RT XP753	L(H)	243	281	284	275	266	62/69
22AYT04	Ozark	L	221	218	227	211	216	63/68
22AYT05	Jupiter	M	163	173	175	133	156	64/67
22AYT06	Lynx	M	199	213	226	191	201	63/68
22AYT07	Titan	M	173	180	204	145	166	63/68
22AYT08	Taurus	M	210	200	247	200	203	62/69
22AYT09	972Sx425-3R4	L(H)	193	215	191	189	199	56/65
22AYT10	988Sx425-3R4	L(H)	219	207	197	190	205	61/68
22AYT11	303Sx20P37544	L(H)	174	190	185	171	178	62/68
22AYT12	318Sx20P37544	L(H)	176	209	204	184	190	58/68
22AYT13	967Sx20P37544	L(H)	218	228	209	236	227	61/68
22AYT14	805Sx20P37572	L(H)	200	238	203	200	213	59/67
22AYT15	129Ax20P37572	L(H)	181	216	193	164	187	58/66
22AYT16	UAS20x377R	L(H)	185	178	164	165	176	57/66
22AYT17	UAS20x396R	L(H)	208	243	222	235	229	61/68
22AYT18	UAS20xTGRT	L(H)	225	290	253	255	257	60/68
22AYT19	TGRT/RU1102134	L	185	193	209	173	184	64/68
22AYT20	DMND/LKST	L	190	214	224	207	204	63/69
22AYT21	DMND/LKST	L	171	208	210	196	192	64/69
22AYT22	DMND/LKST	L	194	229	231	217	214	64/69
22AYT23	ROYJ/RU1501127	L	186	215	223	197	199	62/68
22AYT24	DMND/TGRT	L	183	193	206	164	180	62/68
22AYT25	RU0902125/RU1102034	L	193	206	226	191	197	65/70
22AYT26	RU1201111/DMND	L	207	214	244	223	215	64/70
22AYT27	RU1601070/JEWL	L	180	199	217	201	193	62/68
22AYT28	RU1801173/RU1601070	L	183	207	216	194	195	63/69
22AYT29	RU1401142/RU1201111	L	201	219	233	201	207	63/69
22AYT30	RU1701124/JPTR	M	178	175	196	147	166	65/68
22AYT31	DMND/LKST	L	190	219	246	202	204	64/69
22AYT32	RU1002128/LKST	L	190	216	233	202	203	65/69
22AYT33	RU1501050/07PY828	M	152	179	210	157	163	56/67
22AYT34	RU1501030/DMND	L	190	214	232	218	207	64/69
22AYT35	DMND/LKST	L	194	201	226	191	195	62/68
22AYT36	FRNS/MRMT	L	190	196	220	204	197	65/69
22AYT37	DMND/LKST	L	198	211	242	203	204	65/69
22AYT38	FRNS/TGRT	L	200	207	223	195	201	64/70
22AYT39	DMND/RU1201111	L	204	207	228	204	205	62/68
22AYT40	17AYT06/FRNS	L	191	211	238	216	206	65/69

Continued

Table 1. Continued.

Entry	Pedigree	GT[a]	Grain Yield NE	PT	RB1[b]	RB2[b]	Mean	%HR/ %TR[c]
			(bu./ac)					
22AYT41	16ARPT269/16ARPT272	M	182	216	223	172	190	65/68
22AYT42	16ARPT272/RU1501050	M	194	215	237	175	195	61/70
22AYT43	TITN/Norin 50	M	168	180	192	154	167	64/67
22AYT44	DMND/LKST	L	192	199	216	201	197	63/68
22AYT45	DMND/LKST	L	199	208	237	207	205	63/68
22AYT46	ROYJ/RU1401170	L	200	193	207	182	191	64/69
22AYT47	DMND/RU1201111	L	208	218	252	222	216	65/69
22AYT48	DMND/RU1201136	L	188	202	216	203	198	63/68
22AYT49	RU1201111/DMND	L	219	215	234	217	217	65/70
22AYT50	17AYT06/DMND	L	177	218	223	194	196	65/70
22AYT51	17AYT06/RU1601010	L	203	224	239	213	214	64/69
22AYT52	DMND/RU1201111	L	206	217	229	213	212	63/69
22AYT53	RU1201127/FRNS	L	177	198	207	187	187	65/69
22AYT54	RU1201111/DMND	L	171	187	213	191	183	64/68
22AYT55	17AYT06/DMND	L	188	194	197	199	194	64/68
22AYT56	17AYT06/FRNS	L	195	200	220	204	200	66/70
22AYT57	17AYT06/FRNS	L	182	208	243	217	203	66/71
22AYT58	RU1701084/17AYT006	L	186	203	217	202	197	65/68
22AYT59	17AYT06/RU1601010	L	208	229	252	219	218	65/69
22AYT60	17AYT06/RU1601070	L	196	203	249	208	202	64/68
22AYT61	18AYT62/ROYJ	L	179	195	214	185	186	64/68
22AYT62	17AYT06/FRNS	L	182	193	230	197	191	66/69
22AYT63	17AYT06/RU1601010	L	186	209	228	189	195	65/69
22AYT64	17AYT06/RU1601070	L	185	206	229	188	193	64/68
22AYT65	RU1701084/RU1601070	L	186	208	218	201	198	63/68
22AYT66	JEWL/RU1601070	L	191	192	220	190	191	64/69
22AYT67	JEWL/RU1601070	L	184	207	226	197	196	65/68
22AYT68	JEWL/TGRT	L	189	199	216	186	192	65/69
22AYT69	RU1601070/DMND	L	179	208	221	194	194	63/69
22AYT70	RU1601070/DMND	L	183	204	220	203	197	64/69
22AYT71	RU1701084/JEWL	L	200	200	230	205	202	63/69
22AYT72	RU1701084/RU1601070	L	193	204	225	195	197	63/68
22AYT73	DMND/JEWL	L	181	202	212	198	194	61/67
22AYT74	DMND/RU1201145	L	196	180	222	192	189	65/69
22AYT75	RU1401142/LKST	L	192	199	221	192	194	64/68
22AYT76	RU1201145/DMND	L	183	185	226	192	187	65/69
22AYT77	RU1401142/LKST	L	182	204	226	201	196	65/70
22AYT78	RU1401050/DMND	L	183	212	232	204	200	64/68
22AYT79	RU1401050/DMND	L	196	227	241	207	210	63/68
22AYT80	RU0302143//FRNS/MH63	L	168	157	177	111	145	59/66
c.v.(%)[d]			6.4	5.5	5.3	4.3	5.7	1.2/1.2
$LSD_{0.05}$			19.6	18.4	19.0	13.6	9.3	0.7/0.9

[a] Grain type, L = conventional long-grain, L(H) = long-grain hybrid, and M = conventional medium-grain.
[b] RB1 = planted on 11 April and RB2 = planted on 16 May.
[c] Milling yield, HR = head rice and TR = total rice yield.
[d] Coefficient of variance.

Table 2. Grain and milling yields of 30 Clearfield® (CL) long- and medium-grain breeding lines and commercial checks in the CL advanced elite line yield trial (CAYT) conducted at the University of Arkansas System Division of Agriculture's Pine Tree Research Station (PT) near Colt, and Rice Research and Extension Center (RB) near Stuttgart, 2022.

			Grain Yield				%HR/
Entry	Pedigree	GT[a]	PT	RB1[b]	RB2[b]	Mean	%TR[c]
		------------------(bu./ac)------------------					
22CAYT01	CLL16	CL	197	206	225	209	61/67
22CAYT02	CLL18	CL	203	217	249	223	60/66
22CAYT03	CLM04	CM	201	181	186	189	65/68
22CAYT04	RT 7321 FP	FP(H)	266	255	268	263	60/68
22CAYT05	972SxRU1901129	CL(H)	254	255	246	252	60/68
22CAYT06	979SxRU1901129	CL(H)	217	216	216	216	63/67
22CAYT07	986SxRU1901129	CL(H)	226	231	231	229	61/68
22CAYT08	RU1102034/CL172	CL	210	192	210	204	62/67
22CAYT09	RU1501050/RU1501027	CM	226	228	234	229	64/68
22CAYT10	ROYJ/CL111	CL	202	192	186	193	62/67
22CAYT11	RU1102034/RU1501024*2	CL	209	199	209	206	64/67
22CAYT12	RU1801169/DMND	CL	193	182	188	188	63/68
22CAYT13	RU1801169/LKST	CL	213	192	196	200	61/68
22CAYT14	RU1801169/LKST	CL	168	151	175	164	59/67
22CAYT15	RU1801169/DMND	CL	207	196	194	199	62/68
22CAYT16	RU1102128/RU1501024	CL	203	190	171	188	62/67
22CAYT17	RU1501050/RU1501027	CM	198	208	187	197	63/68
22CAYT18	RU1601167/CL172	CL	192	181	171	181	60/66
22CAYT19	16ARPT269/CLM04	CM	160	171	162	165	64/67
22CAYT20	DMND/CLL15	CL	192	175	193	187	63/69
22CAYT21	DMND/RU1601127	CL	221	206	234	220	61/67
22CAYT22	RU1102034/CL153	CL	205	211	220	212	65/69
22CAYT23	16AYT045/CL172	CL	206	213	212	210	63/68
22CAYT24	RU1801169/JEWL	CL	185	195	192	190	64/68
22CAYT25	16AYT045/CL172	CL	209	184	189	194	62/67
22CAYT26	NPTN/RU1501027	CM	205	205	221	211	63/67
22CAYT27	16ARPT269/RU1601050	CM	196	200	195	197	63/67
22CAYT28	16ARPT271/15CSIT769	CM	212	187	208	202	59/67
22CAYT29	RU1201111/CL172	CL	200	204	212	205	64/69
22CAYT30	RU1601050/CFFY	CM	198	193	191	194	63/69
c.v.(%)[d]			5.6	5.8	4.6	5.7	1.9/1.0
$LSD_{0.05}$			18.7	18.9	15.3	10.8	1.1/0.6

[a] Grain type, CL = Clearfield® long-grain, CL(H) = Clearfield® hybrid, CM = Clearfield® medium-grain, and FP (H) = RiceTec Fullpage® hybrid.

[b] RB1 = planted on 4 April and RB2 = planted on 28 April.

[c] Milling yield, HR = head rice and TR = total rice yield.

[d] Coefficient of variance.

Table 3. Grain and milling yields of 20 Provisia® (PV) long-grain breeding lines and commercial checks in the advanced PV elite line yield trial (PAYT) conducted at the University of Arkansas System Division of Agriculture's Pine Tree Research Station (PT) near Colt, Northeast Research and Extension Center (NE) at Keiser, and Rice Research and Extension Center (RB) near Stuttgart, 2022.

		Grain Yield					%HR/
Entry	Pedigree	NE	PT	RB1[a]	RB2[a]	Mean	%TR[b]
		------------------(bu./ac)------------------					
22PAYT01	PVL02	177	195	155	119	162	66/71
22PAYT02	PVL03	167	184	192	199	192	63/70
22PAYT03	(RU1102131/RU0903141)*2/HPHI2//…	162	218	170	204	198	61/68
22PAYT04	(RU1102131/RU0903141)*3/HPHI2	163	203	171	208	194	63/69
22PAYT05	(RU1102131/RU0903141)*3/HPHI2	164	196	170	208	192	63/68
22PAYT06	(RU1102131/RU0903141)*3/HPHI2	173	202	178	216	199	61/67
22PAYT07	(RU1102131/RU0903141)*3/HPHI2	196	210	183	226	206	63/69
22PAYT08	(RU1102131/RU0903141)*3/HPHI2	171	201	134	198	178	64/69
22PAYT09	(RU1102131/RU0903141)*3/HPHI2	167	201	157	200	186	62/68
22PAYT10	(RU1102131/RU0903141)*2/HPHI2//…	175	199	176	188	188	60/67
22PAYT11	(RU1102131/RU0903141)*3/HPHI2	165	212	179	207	199	62/68
22PAYT12	(RU1102131/RU0903141)*3/HPHI2	163	209	172	212	198	62/67
22PAYT13	RU1701185*3/HPHI2	165	202	195	194	197	66/70
22PAYT14	(RU1102131/RU0903141)*3/HPHI2	177	197	170	199	189	63/68
22PAYT15	(RU1102131/RU0903141)*3/HPHI2	162	187	172	217	192	64/69
22PAYT16	(RU1102131/RU0903141)*3/HPHI2	156	189	167	200	185	64/68
22PAYT17	(RU1102131/RU0903141)*3/HPHI2	163	194	177	207	193	61/67
22PAYT18	(RU1102131/RU0903141)*3/HPHI2	163	195	167	199	187	63/68
22PAYT19	(RU1102131/RU0903141)*3/HPHI2	161	196	145	206	182	63/69
22PAYT20	(RU1102131/RU0903141)*3/HPHI2	172	195	164	216	192	64/70
c.v.(%)[c]		5.2	9.6	5.9	6.0	7.1	1.0/1.5
$LSD_{0.05}$		14.8	22.9	16.5	17.1	9.5	0.5/0.7

[a] RB1 = planted on 4 April and RB2 = planted on 28 April.
[b] Milling yield, HR = head rice and TR = total rice yield.
[c] Coefficient of variance.

Development of Superior Medium-Grain and Long-Grain Rice Varieties for Arkansas and the Mid-South

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Abstract

Reflecting recent changes of the Arkansas rice industry and streamlining the delivery of new and improved rice varieties to Arkansas rice growers, the medium-grain rice breeding project has expanded its research areas and breeding populations to include conventional, Clearfield®, and Provisia® medium-grain and long-grain rice as well as hybrid rice. The newest elite breeding lines/varieties from collaborating programs, as well as lines with diverse genetic origins, will be actively collected, evaluated, and incorporated into current crossing blocks for programmed hybridization. To improve the efficiency and effectiveness of the program, maximum mechanized-operation, multiple generations grown in the winter nursery, and new technologies such as genomic selection are vigorously pursued.

Introduction

Medium-grain rice is an important component of Arkansas rice. Arkansas ranks second in medium-grain rice production in the United States only behind California. During 2011–2020, an average of 0.17 million acres medium-grain rice was grown annually, making up about 13% of total state rice acreage (USDA-ERS, 2022). Even with the rapid adoption of hybrid rice from the private sector during last 2 decades, about 20% Arkansas rice acreage was planted to long-grain pure-line varieties, such as Diamond, Jewel, and CLL16. Improved high-yielding semi-dwarf long-grain rice can also be directly adopted by the newly established hybrid breeding program. Since genetic potential still exists for further improvement of current varieties, rice breeding efforts must continue to maximize yield and quality for the future.

The inter-subspecies hybrids between *indica* male sterile lines and tropical *japonica* restorer/pollinator lines, which were first commercialized in the United States in 1999 by RiceTec, have a significant yield advantage over conventional pure-line varieties (Walton, 2003). However, further improvement of hybrid rice is critically needed to address its inconsistent milling yield, suboptimal grain quality, lodging susceptibility, pubescent leaf and sheath, volunteer weedy rice out of dormant residue seeds, and high seed cost. A public hybrid rice research program that focuses on developing adapted lines (male sterile, maintainer, and restorer lines) will be instrumental in overcoming such constraints.

Procedures

Potential parents for the breeding program are evaluated for the desired traits. Cross combinations are programmed that combine desired characteristics to fulfill the breeding objectives. Marker-assisted selection (MAS) will be carried out on backcross or top-cross progenies for simply inherited traits such as herbicide traits, blast resistance, and physicochemical characteristics. Meanwhile, genomic selection will be attempted on mid-generation breeding lines that are reasonably uniform. Segregating populations are planted, selected, and advanced at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC) near Stuttgart, Ark. and the winter nursery near Lajas, Puerto Rico. Pedigree and modified single seed descent will be the primary selection technologies employed. A significant number of traits will be considered during this stage of selection including grain quality (shape and appearance), plant stature, lodging resistance, disease (blast, sheath blight, and panicle blight) resistance, earliness, and seedling vigor. Promising lines with a good combination of these characteristics will be further screened in the laboratory for traits such as kernel size and shape, grain chalkiness, and grain uniformity. Initial milling evaluation will be conducted on bulked panicle rows prior to their inclusion in the preliminary yield trial to eliminate ones with evident quality problems in order to maintain the standard U.S. rice quality of different grain types/market classes. Yield evaluations include the preliminary Stuttgart Initial Yield Trials (conventional SIT, Clearfield® CSIT, and Provisia® PSIT) at RREC and the Advanced Elite Line Yield Trial (conventional AYT, Clearfield® CAYT, and Provisia® PAYT at RREC, Pine Tree Research Station (PTRS) near Colt, Ark., Northeast Research and Extension Center (NEREC) in Keiser, Ark, and Northeast Rice Research and Extension Center in Harrisburg, Ark. Advanced yield trials also include the Arkansas Rice Variety Advancement Trials (ARVAT) and on-farm Arkansas Rice Performance Trials (ARPT) conducted by Jarrod Hardke, the Arkansas rice agronomy specialist, at 6–10

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locations in rice-growing regions across the state, and the Uniform Regional Rice Nursery (URRN) conducted in cooperation with public rice breeding programs in Arkansas, California, Louisiana, Mississippi, and Texas. Promising advanced lines will be further evaluated in the new Pre-commercial (PC) trial conducted at 25–30 locations in Arkansas, Louisiana, and Texas, as well as by cooperating projects for their resistance to sheath blight, blast, and panicle blight, grain and cooking/processing quality, and nitrogen fertilizer requirements. All lines entered in the SIT, CSIT, or PSIT and beyond will be planted as head rows for purification and increase purposes.

Results and Discussion

The field research in 2022 included 940 transplanted or drill-seeded F_1 populations, 1,063 space-planted F_2 populations, and 87,200 panicle rows ranging from F_3 to F_7. Visual selection on over 1 million individual space-planted F_2 plants resulted in a total of 60,000 panicles that will be individually processed and grown as F_3 panicle rows in 2023. A total of 4,504 panicle rows were selected for advancement to next generation; while 1,797 rows appeared to be uniform and superior to others, therefore were bulk-harvested by hand as candidates of 2023 SIT, CSIT, and PSIT trials. In 2022 CSIT, we evaluated 406 new breeding lines, which included 336 CL long-grain and 70 CL medium-grain breeding lines. Of 515 new conventional breeding lines tested in the SIT trial, 387 were long-grain lines, 83 medium-grain lines, and 45 restorer or maintainer lines for hybrid rice breeding. A total of 387 new Provisia lines were tested in the PSIT trial, which include 375 PV long-grain and 12 PV medium-grain lines. By outsourcing, an unprecedented 5,775 lines, rows, and plants of both pure-line and hybrid were genotyped using a very selective panel of 80 molecular markers, and about a half million data points were generated, which is much more than what our in-house molecular lab generated in last ten years combined. Most importantly, this was achieved in a 2–4 weeks turnaround time and a price tag of less than $15,000. An 80-entry Advanced Elite Line Yield Trial (AYT) was conducted at NEREC and PTRS in addition to RREC, while a 30-entry CAYT and a 20-entry PAYT were tested at RREC and PTRS, which were treated with 2X recommended rate of NewPath and Provisia herbicides, respectively. A number of breeding lines showed yield potential similar to or better than the check varieties in 2022 SIT, CSIT, and PSIT trials (Tables 1–5). Thirty-five advanced experimental lines were evaluated in the statewide ARVAT trial and results can be found in Arkansas Rice Variety Advancement Trials, 2022 in this publication (page 49). Three Puerto Rico winter nurseries consisting of 15,000 7-foot rows were planted, selected, and turned around during 2022 off-season, and will be harvested in spring 2023. In cooperation with Horizon Ag, a 6.5-acre breeder seed production of the first ever RREC developed Provisia long-grain line RU2201021 was conducted in Puerto Rico in November and will be harvested in late April 2023 to ramp up the seed production for the potential commercial launch in 2024. A total of 950 new crosses were made to incorporate desirable traits from multiple sources into adapted Arkansas rice genotypes, which included 406 conventional long-grain, 219 conventional medium-grain, and 12 conventional short-grain crosses, 151 PV long-grain and 19 PV medium-grain crosses, and 92 CL long-grain and 51 CL medium-grain crosses.

Both Ozark and Taurus that were released in late 2021 continued having the strong performance in 2022 yield trials. Foundation seed of the two have been produced and will be available to Arkansas seed rice growers in 2023. A new CL medium-grain RU2101234 and a conventional medium-grain RU1901165 have been approved for release in late 2022, and both of them consistently showed a significant yield advantage over CLM04 and Jupiter in yield trials across Mid-South. One hundred fifty-eight breeding lines that outperformed commercial check varieties in AYT, CAYT, PAYT, CSIT, PSIT, and SIT trials were selected and further evaluated in the laboratory as candidates for 2023 advanced yield trials including ARVAT, AYT, CRT, PC, and URRN.

Practical Applications

Successful development of medium-grain varieties Taurus, Titan, CLM04, and Lynx, and long-grain varieties Ozark and CLL15 offers producers options for variety and management systems in Arkansas rice production. Continued utilization of new germplasm through exchange and introduction remains important for Arkansas rice improvement.

Acknowledgments

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Table 1. Performance of selected Clearfield long-grain experimental lines and check varieties in the Clearfield® Stuttgart Initial Trial (CSIT) at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center near Stuttgart, 2022.

Variety/Line	Pedigree	Seedling vigor[a]	Days to 50% heading	Plant height	Yield	Milling[b]
				(in.)	(bu./ac)	(%HR/%TR)
22CSIT1323[d]	RU1801169/LKST	4.0	85	41	225	59/68
22CSIT1409[d]	14SIT758/RU1601133	3.5	85	41	222	64/69
22CSIT1368[d]	17SIT639/RU1801101	4.0	85	44	222	61/69
22CSIT1157[c]	CLL15/RU1801097	3.0	88	39	222	55/68
22CSIT1413[d]	CL153/RU1501124	4.0	84	43	218	64/71
22CSIT1362[d]	RU1701185/17AYT026	4.0	87	40	218	61/68
22CSIT1075[c]	RU1102134/RU1601170	3.0	82	39	218	61/69
22CSIT1293[d]	17AYT048/CLL15	3.5	83	43	218	58/68
22CSIT1076[d]	RU1102137/16AYT039	3.0	82	37	217	56/69
22CSIT1406[d]	16AYT052/CLL15	4.0	82	39	216	63/71
22CSIT1327[d]	RU1801169/RU1201111	3.5	85	42	216	61/69
CLL16[c]	CLL16	3.0	88	42	215	60/67
CLL19[c]	CLL19	3.5	82	39	198	n/a
CLL16[d]	CLL16	3.0	89	44	207	n/a
CLL18[d]	CLL18	4.0	89	45	212	n/a

[a] A subjective 1–7 rating taken at emergence, 1 = perfect stand and 7 = no stand.
[b] Milling yield HR = head rice and TR = total rice; n/a = not available.
[c] Planted on 4 April.
[d] Planted on 19 April.

Table 2. Performance of selected Clearfield medium-grain experimental lines and check varieties in the Clearfield® Stuttgart Initial Trial (CSIT) at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center near Stuttgart, 2022.

Variety/Line	Pedigree	Seedling vigor[a]	Days to 50% heading	Plant height	Yield	Milling[b]
				(in.)	(bu./ac)	(%HR/%TR)
22CSIT1098[c]	RU1601050/15CSIT752	3.0	83	37	224	46/66
22CSIT1114[c]	16ARPT255/RU1601050	3.0	82	33	211	54/66
22CSIT1039[c]	TITN/RU1501096	3.0	83	39	205	53/67
22CSIT1099[d]	RU1601050/CFFY	3.5	83	37	201	40/67
22CSIT1146[c]	16SIT1000/RU1501111	3.0	79	39	196	n/a
22CSIT1097[c]	RU1601050/RU1701050	3.0	84	34	196	n/a
22CSIT1082[c]	16AYT059/16AYT049	3.0	79	39	195	n/a
22CSIT1041[c]	14SIT891/RU1501099	3.0	81	38	194	n/a
22CSIT1369[d]	RU1501096/17CSIT548	4.0	90	42	196	62/69
CLM04[c]	CLM04	3.0	86	38	195	65/67
CLM04[d]	CLM04	3.0	86	43	191	n/a

[a] A subjective 1–7 rating taken at emergence, 1 = perfect stand and 7 = no stand.

[b] Milling yield HR = head rice and TR = total rice; n/a = not available.

[c] Planted on 4 April.

[d] Planted on 19 April.

Table 3. Performance of selected conventional medium-grain experimental lines and check varieties in the Stuttgart Initial Trial (SIT) at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center near Stuttgart, 2022.

Variety/Line	Pedigree	Seedling vigor[a]	Days to 50% heading	Plant height	Yield	Milling[b]
				(in.)	(bu./ac)	(%HR/%TR)
22SIT150[c]	16AYT058/16ARPT255	3.5	84	37	223	47/68
22SIT157[c]	16AYT058/17AYT060	3.0	86	35	222	49/67
22SIT003[c]	16ARPT255/17AYT060	3.0	85	36	218	54/67
22SIT005[c]	RU1701124/16ARPT255	3.0	81	36	216	59/67
22SIT163[c]	RU1701130/16SIT1003	3.5	80	35	211	54/68
22SIT466[d]	18AYT79/18AYT76	4.0	83	38	219	60/69
22SIT462[d]	18AYT77/RU1801237	4.0	87	34	203	60/68
22SIT434[d]	16ARPT271/17SIT978	4.0	88	38	200	n/a
Taurus[c]	Taurus	3.0	81	36	211	n/a
Titan[c]	Titan	3.0	81	35	184	n/a
Taurus[d]	Taurus	3.5	83	38	210	n/a

[a] A subjective 1–7 rating taken at emergence, 1 = perfect stand and 7 = no stand.

[b] Milling yield HR = head rice and TR = total rice; n/a = not available.

[c] Planted on 4 April.

[d] Planted on 28 April.

Table 4. Performance of selected Conventional long-grain experimental lines and check varieties in the Stuttgart Initial Trial (SIT) at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center near Stuttgart, 2022.

Variety/Line	Pedigree	Seedling vigor[a]	Days to 50% heading	Plant height	Yield	Milling[b]
				(in.)	(bu./ac)	(%HR/%TR)
22SIT238[d]	RU1701084/17SIT556	3.0	90	43	248	62/70
22SIT041[c]	DMND/RU1201111	4.0	84	46	246	59/70
22SIT075[c]	RU1201111/DMND	3.5	85	40	245	62/71
22SIT042[c]	DMND/RU1201111	3.5	86	43	244	61/70
22SIT095[c]	17AYT06/FRNS	3.5	83	42	242	61/71
22SIT023[c]	DMND/LKST	4.0	84	44	238	57/69
22SIT111[c]	17AYT06/RU1601070	3.5	85	44	236	60/70
22SIT225[d]	RU1701084/JEWL	3.0	90	44	233	64/70
22SIT120[c]	RU1701185/DMND	4.0	87	45	231	63/70
22SIT076[c]	RU1201111/DMND	3.5	87	44	229	59/69
22SIT313[e]	RU1601070/18AYT58	3.0	90	44	225	57/72
22SIT368[e]	17SIT556/RU1201111	3.0	91	44	221	58/71
Ozark[c]	Ozark	3.5	85	43	217	n/a
Ozark[e]	Ozark	4.0	89	43	210	n/a
DG263L[e]	DG263L	3.0	83	38	213	n/a

[a] A subjective 1–7 rating taken at emergence, 1 = perfect stand and 7 = no stand.
[b] Milling yield HR = head rice and TR = total rice; n/a = not available.
[c] Planted on 4 April.
[d] Planted on 19 April.
[e] Planted on 28 April.

Table 5. Performance of selected Provisia® (PV) experimental lines and check varieties in the PV Stuttgart Initial Trial (PSIT) at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center near Stuttgart, 2022.

Entry	Variety/line	Grain type[a]	Seedling vigor[b]	Days to 50% heading	Plant height	Yield	Milling[c]
					(in.)	(bu./ac)	(%HR/%TR)
22PSIT2027[d]	23AR2114	PVL	4.0	88	46	252	59/68
22PSIT2346[e]	23AR2134	PVL	4.0	86	45	248	60/68
22PSIT2350[e]	23AR2211	PVL	3.5	85	45	241	62/70
22PSIT2344[e]	23AR2132	PVL	3.5	86	46	240	59/67
22PSIT2291[e]	23AR2112	PVL	4.0	84	45	240	59/67
22PSIT2360[e]	23AR2137	PVL	3.0	84	47	237	60/67
22PSIT2025[d]	23AR2109	PVL	3.5	85	44	237	57/66
22PSIT2097[d]	22PSIT2097	PVL	3.0	86	45	237	48/68
22PSIT2345[e]	23AR2133	PVL	4.0	87	48	236	61/67
22PSIT2355[e]	23AR2135	PVL	4.0	85	44	236	61/67
22PSIT2294[e]	23AR2126	PVL	3.5	84	50	235	61/69
22PSIT2259[e]	23AR2205	PLM	3.5	86	46	211	57/66
PVL03[d]	PVL03	PVL	3.0	87	39	199	63/70
PVL03[e]	PVL03	PVL	3.0	88	47	213	na

[a] Grain type: PVL = Provisia long-grain and PVM = Provisia medium-grain.
[b] A subjective 1–7 rating taken at emergence, 1 = perfect stand and 7 = no stand.
[c] Milling yield HR = head rice and TR = total rice; n/a = not available.
[d] Planted on 4 April.
[e] Planted on 19 April.

Rice Breeding and Pathology Technical Support

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Abstract

Disease resistance is a valuable trait that rice breeders utilize at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC) toward selection of preliminary and advanced breeding lines, as well as, in development of new rice varieties. Assessment of rice diseases under field and greenhouse environments is provided by the RREC rice breeding and pathology technical support group. Evaluation for disease resistance starts from early generation lines up to the release of rice varieties. Breeding materials are evaluated for sheath blight under field conditions at RREC with artificial inoculum. Assessment for neck blast is conducted in the field at the University of Arkansas System Division of Agriculture's Pine Tree Research Station (PTRS), while leaf blast testing is conducted in the greenhouse at RREC. Large amounts of inoculum for tested pathogens are prepared in the lab using various protocols and applied to plants using dispersal methods that have explicit protocols. Data generated from screening helps to select lines that are used either to transfer genes for resistance into adapted and high-yielding varieties or to advance entries for further agronomic testing. The breeding and pathology technical support group also assists the extension rice pathology projects in conducting applied research. Various pathogens are also grown for field inoculum to further understand and better manage major prevailing and recently emerging diseases. These endeavors have included collaborative interdepartmental, industry, and multi-state research.

Introduction

Rice breeders and pathologists work together to develop varieties having desirable agronomic traits and disease resistance. Disease evaluation of rice against major diseases is essential for a successful breeding program and begins in the early generations of plant selection. Lines having desirable disease resistance but not meeting the desired agronomic levels for release can become parents to develop other new varieties.

Rice blast, caused by *Magnaporthe grisea* (T.T. Herbert) M.E. Barr, is still a damaging disease in severe disease years, causing significant yield loss. Emphasis is given to evaluate breeding materials for both leaf and neck blast. Rice seedlings from the greenhouse are used to evaluate leaf blast, while more mature plants are tested in the field to determine resistance to neck blast. Screening of rice in greenhouse and field for blast susceptibility requires favorable environmental conditions preceding and following inoculation for the pathogen to cause disease.

All Uniform Regional Rice Nursery (URRN), Arkansas Variety Advancement Trials (ARVAT), as well as, the advanced and selected preliminary breeding lines from the Long-Grain Rice Breeding Project are assessed in the field at RREC for sheath blight (*Rhizoctonia solani* Kuhn), another devastating fungal disease of rice. To date, no major genes have been identified that render complete resistance to this pathogen.

Procedures

Evaluation of Breeding Materials for Blast Resistance in the Greenhouse

The URRN, ARVAT, Stuttgart Initial Test–A (SIT-A), and the Advanced Yield Trials for Long Grain (LG AYT), Clearfield (CLAYT), and Aromatics (AROAYT) collectively totaled 268 entries and were evaluated for resistance to leaf blast. Tests were replicated to generate three disease observations per entry to ensure the quality of data. Over 82 flats of soil were prepared to produce 3 to 4 leaf seedlings planted as hill plots. All lines, except for SIT-A test were individually assessed with individual spore suspensions of *M. grisea* races: IB-1, IB-17, IB-49, IC-17, and IE-1K. Plants in the SIT-A test were sprayed with a modified inoculation procedure using a mixture of races without IE-1K. The IE-1K race was tested separately due to its aggressiveness to produce large elongated lesions on the leaves. Disease growth and inoculum production were generated using previously described procedures (Kelsey, et al., 2016). Disease data were collected 7 to 10 days after inoculation using both a disease severity rating scale of 0 (healthy tissue) to 9 (elongated necrotic tissue) and an incidence scale of 1 (single leaf or lesion) to 100 (all leaves necrotic with multiple lesions) to score relative amounts of lesion coverage.

Evaluation of Breeding Materials for Sheath Blight and Blast in the Field

For sheath blight tolerance, a nursery at RREC was planted on 4 May with entries of URRN, ARVAT, LGAYT, CLAYT, and AROAYT. Five replications were planted to establish 1,320 hill plots with controls. On 12 July, plants (at panicle initiation stage) were hand inoculated with approximately 16 gallons "slow" growing pathogenic *R. solani* isolates at the rate of 24 g (~1 oz) per 6 hill plots. About six weeks later, vertical disease progress was visually scored in proportion to the height of each entry using a 0 to 9 scale where 0 was no vertical disease progress and 9 showed infection of flag leaf and head.

The PTRS nursery, to evaluate neck blast disease, was established on 19 May in a secluded area having a forested border on

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three sides of the test. Field corn was planted on the open south side to act as a windbreak and isolate the test from the rest of the field area. The study included 119 entries from ARVAT and URRN collection in hill plots with 6 replications (totaling approximately 860 hill plots including checks) surrounded by a mixture of susceptible lines used as a spreader to encourage spore multiplication and disease spread to adjacent rice plants. The hill plots were started as a flooded paddy but for purposes of inoculation were later changed to upland conditions. Approximately 125 gallons of corn chops/rough rice media was prepared using a mixture of 4 of the pathogen races used in greenhouse leaf blast assessment that are common in Arkansas. IE-1K was omitted since there has not been any recorded evidence of this race in St. Francis County where the PTRS is located. The nursery was inoculated 4 times over the course of the season: 13 July (tillering), 22 July (after panicle differentiation), 5 August (mid boot), and 12 August (early split). The semi-dried seed media was broadcasted to inoculate rice plant entries and spreader material. When entries were fully headed, disease assessment was made by counting the number of panicles appearing with neck blast.

Assistance to Extension Rice Pathology

Breeding pathology technical support provided planting and maintenance of 14 field experiments (3.4 acres) designed to collect data for rice disease suppression/control of early season seedling and sheath blight diseases. In collaboration with chemical industries, approximately 200 gallons of *R. solani* AG1-1A inoculum was prepared and applied to 412 rice plots for 103 fungicide efficacy treatments. Seed treatment studies incorporated 40 g of *R. solani* AG9 into 48 envelopes with fungicide/insecticide treated seed and 40 g of *Pythium* sp. was added to 60 envelopes with fungicide/insecticide treated seed. Collectively, these 108 envelopes were used to evaluate 22 fungicide seed treatments. Vigor, seeding stand count, and yield data were collected for these industry tests.

In the breeder fields at RREC, over 520 plots of advanced long-grain and aromatic breeding lines were visually assessed for naturally occurring major rice diseases. Field evaluation of 512 agronomy field plots of both ARVAT and Arkansas Rice Performance Trial (ARPT) also at RREC was scouted for the presence of naturally occurring rice diseases. Finally, 12 rice lines from Nutrien Ag Solutions were field assessed for their tolerance to sheath blight and blast.

Results and Discussion

Of the 268 experimental lines tested for leaf blast in the greenhouse with 5 individual races of the pathogen, several entries received low scores and were categorized as disease resistant/tolerant (Table 1). Review of leaf blast incidence and severity data was useful for identifying entries with mixed seed or possible segregation of resistance genes.

Disease assessment of rice for resistance/tolerance to sheath blight was completed for the breeding program. Several tolerant entries to sheath blight were identified (Table 2). Unfortunately, meaningful neck blast data was not obtained due to the lack of distinctive symptoms present on panicles of susceptible checks throughout the nursery. Although numerous attempts to establish disease with lab-produced inoculum were attempted, the prevailing hot and dry field conditions were believed to have discouraged disease development.

The breeding–pathology technical support group aided in the successful applied research of the extension rice pathology program. Activities were completed for all funded research programs, which included field activities of rice planting to harvest; laboratory of inoculum production and preparation of two-liter chemical spray solutions for Mud Master spray equipment; and greenhouse with production of rice seedlings and inoculation with pathogenic fungal spores for leaf blast screening evaluation.

Practical Applications

The rice breeding-pathology technical support group provides disease data to the breeding program to minimize the most susceptible materials from advancing. It assists breeders in selecting and developing new high-yielding cultivars with improved disease resistance. Technical support is fundamental to the extension plant pathology program by assisting in applied research and promoting practical information to benefit rice producers. The technical support group is vigorously supporting the breeder and extension rice pathology programs to improve rice production for Arkansas growers.

Acknowledgments

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Table 1. Number of entries rated disease tolerant[a] for 2022 greenhouse leaf blast testing at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center, Stuttgart.

Test[b]	Total Entries	IE1K	IC17	IB17	IB49	IB1
URRN	49	11	19	21	20	16
ARVAT	70	20	20	20	15	15
LG AYT	50	1	6	1	6	9
CL AYT	33	4	6	13	12	14
ARO AYT	14	2	10	4	3	3
			Combined individual races "bulk" tested			
SIT-A	52	5	19			

[a] Disease severity rating scale of zero (no disease) to four (small diamond shaped lesion with ashy center).

[b] URRN = Uniform Regional Rice Nursery; ARVAT = Arkansas Variety Advancement Trial; LG AYT = Advanced Yield Trial for Long Grain; CL AYT = Advanced Yield Trial for Clearfield; ARO AYT = Advanced Yield Trial for Aromatics.

Table 2. Number of entries rated sheath blight tolerant in 2022 field nursery at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center, Stuttgart.

Test[b]	Total entries screened	Entries tolerant using "slower" growing isolate[a]
URRN	49	17
ARVAT	70	32
LG AYT	50	27
CL AYT	33	18
ARO AYT	14	10

[a] Rating scale of 0 (no disease) to 9 (severe disease) was used. A "6" represents disease progression about 60% up the plant and considered tolerant for average scores of 6.3 or less.

[b] URRN = Uniform Regional Rice Nursery; ARVAT = Arkansas Variety Advancement Trial; LG AYT = Advanced Yield Trial for Long Grain; CL AYT = Advanced Yield Trial for Clearfield; ARO AYT = Advanced Yield Trial for Aromatics.

Comparison of Foliar Insecticides and Application Timing for Control of Rice Water Weevil

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Abstract

Rice water weevil is the most destructive insect pest of flooded rice in the mid-South. Currently, insecticide seed treatments are the main control strategy used to manage this pest. However, a large percentage of rice acres in Arkansas still receive subsequent foliar applications for this pest. Studies were conducted in 2021 and 2022 at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center near Stuttgart Ark., and the Pine Tree Research Station near Colt, Ark. to determine the efficacy of multiple foliar insecticides for control of rice water weevil. Insecticides tested included: Lambda-Cy, Belay, Vantacor, and Endigo ZCX. Both a pre-flood and post-flood application timing was also evaluated. In general, preflood applications performed over 30% better than post flood applications with respect to rice water weevil efficacy. All insecticides performed better than the untreated, with pre-flood applications of Belay, Vantacor, and Endigo ZCX performing the best. No differences were observed between treatments or application timing with respect to yield.

Introduction

Rice water weevil, *Lissorhoptrus oryzophilus* Kuschel, is the number one pest of flooded rice, *Oryza sativa*, in the mid-South (Taillon et al., 2013). Both the adult and immature stages of this pest feed on rice, however the larval stage is the only stage to cause economic losses. Adults migrate into rice fields after the permanent flood has been established. Adults feed on rice leaves, leaving white longitudinal scars. This feeding is superficial and does not cause yield loss. Typically, within 7 to 10 days after entering the field, adult rice water weevil mate and lay eggs. After egg hatching, larvae move into the soil and begin feeding on the roots of the rice plants. This feeding reduces nutrient uptake and ultimately reduces yield.

Currently, the main control strategy for managing rice water weevil is the use of insecticide seed treatments (Taillon et al., 2014, 2016, and 2018). The two classes of insecticide seed treatments labeled for use in rice are neonicotinoids and diamides. The neonicotinoids, thiamethoxam (CruiserMaxx Rice, Syngenta) and clothianidin (NipsIt Inside, Valent USA) dominate the rice landscape, however they have limited residual compared to the diamides chlorantraniliprole (Dermacor X-100, Corteva) and cyantraniliprole (Fortenza, Syngenta). With the current strategy of planting rice early, late Mar through early May, to optimize yield potential, the permanent flood is not applied to rice until 40 or more days after planting. When this occurs, reduced control of rice water weevil with neonicotinoid seed treatments is observed. In many cases, when this occurs growers will make foliar insecticide applications to help manage rice water weevils.

Foliar insecticides are used to target adult rice water weevils as they migrate into rice fields (Taillon et al., 2016). Application timing is critical, due to the short time period between adult migration and egg lay occurring. Currently there are very few insecticide classes available for in-season use for rice water weevil control. The classes labeled are pyrethroids (lambda-cyhalothrin, zeta-cypermethrin, and gamma-cyhalothrin) and a neonicotinoid (clothianidin, Belay, Valent USA). The objective of this study was to determine the efficacy and residual control of select foliar insecticides for control of rice water weevil and the impact application can have on control.

Procedures

Foliar insecticides studies were conducted in 2021 and 2022 at the University of Arkansas System Division of Agriculture's Pine Tree Research Station (PTRS) near Colt, Ark., and at the Rice Research and Extension Center (RREC) near Stuttgart, Ark. Plots were planted at PTRS and RREC between the last week of Apr and first week of May each year. At PTRS, a hybrid cultivar RT 7521 FP was planted at 20 lb/ac, and at RREC a pure-line cultivar CLL16 was planted at 60 lb/ac. All seed only received a fungicide seed treatment package. Insecticide applications were made using a backpack sprayer outfitted with a 4.5 ft boom with TeeJet hollow cone nozzles on 15 in spacing calibrated to deliver 10 GPA at 40 PSI. Preflood applications were made within 24 h of the permanent flood being applied to the field. The Postflood applications were made 24 h after permanent flood establishment. Insecticides used in these studies included: Lambda-Cy 3.65 oz/ac, Vantacor 1.2 oz/ac, Belay 4.5 oz/ac, and Endigo ZCX 5 oz/ac.

Rice water weevil larvae were evaluated by taking 3 core samples per plot with a 4-inch core sampler 21 days after permanent flood establishment. Samples were evaluated at the Lonoke

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Agricultural Extension and Research Center. Each core was washed into a 40-mesh sieve with water to loosen soil and remove larvae from the roots. The sieve was immersed in a warm saturated saltwater solution which caused the larvae to float for counting. Yield samples were collected and adjusted to 12% moisture. All data were processed using PROC GLIMMIX in SAS v. 9.4 (SAS Institute, Cary, N.C.) with alpha level of 0.05.

Results and Discussion

Differences in rice water weevil control were observed between preflood and postflood application timings ($P < 0.01$). Higher efficacy was observed in the preflood application (58.7%) compared to the post flood application (24.4%). While no yield difference ($P = 0.40$) was observed between application timing, a trend was observed that preflood applications (6.9%) had higher mean yields than postflood applications (4.9%) compared to the untreated.

Similar results were observed for insecticide treatments (Table 1). Preflood applications of Belay, Vantacor, and Endigo ZCX performed better than all other treatments with respect to rice water weevil control. No differences were observed among the post flood applications regardless of insecticide product. A general trend of higher yields for preflood timings compared to post flood timings for most insecticides tested was observed, however no differences were observed.

Practical Applications

Based off these tests, growers should consider preflood applications over postflood applications. This is not a recommendation for every acre though. Preflood applications only have a fit in scenarios where a history of high rice water weevil pressure is known, and if a neonicotinoid seed treatment was used and the permanent flood is applied 35 days or longer after planting. It will not be practical or cost-efficient to make preflood applications on every acre.

Acknowledgments

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Table 1. Percent increase in rice water weevil control and yield compared to the untreated control for multiple insecticides used in foliar rice water weevil studies conducted at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center and Pine Tree Research Station in 2021 and 2022.

Insecticide and Rate	Application Timing	% RWW Reduction	%Yield Increase‡
Lambda-Cy 3.65 oz/ac	Preflood	23.0 b†	6.0
Lambda-Cy 3.65 oz/ac	Post Flood	22.1 b	6.7
Belay 4.5 oz/ac	Preflood	79.1 a	10.1
Belay 4.5 oz/ac	Post Flood	30.1 b	3.6
Vantacor 1.2 oz/ac	Preflood	79.8 a	7.1
Vantacor 1.2 oz/ac	Post Flood	26.5 b	3.0
Endigo ZCX 5 oz/ac	Preflood	57.2 a	4.3
Endigo ZCX 5 oz/ac	Post Flood	22.9 b	6.8
P-value		<0.01	0.82

† Treatments with the same letter are not different according to Duncan's numerical range test at $\alpha = 0.05$.

‡ Percent yield increase compared to fungicide only treated seed.

Effects of Defoliation on Hybrid and Pure-Line Rice Cultivars

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Abstract

Armyworms are commonly found in rice fields in the mid-southern U.S. and have the potential to cause severe defoliation to the rice crop. Infestations can occur at all growth stages of rice. A defoliation threshold was developed in pure-line rice recently, hybrid cultivars need to be evaluated. Studies were conducted in 2022 where both pure-line and hybrid rice were mechanically defoliated at 100% with a weed eater at the two-three leaf, early tiller, late tiller, and green ring growth stages across three planting dates. Less yield loss was observed in the Apr planting in the hybrid cultivar compared to the pure-line regardless of growth stage. Similar yield losses were observed at the two-three leaf and early tiller growth stages between hybrid cultivars and pure-line cultivars at the May and Jun plantings. The hybrid cultivar had less yield loss compared to the pure-line cultivar at the late tiller and green ring growth stages for May and June plantings. This data suggest that thresholds could potentially be increased in hybrids compared to conventional cultivars.

Introduction

Armyworms are an occasional pest of rice in the mid-South. The 2 most common species of armyworms in rice production are true armyworms (*Psuedoletia unipuncta*) and fall armyworms (*Spodoptera frugiperda*) (Lorenz et al., 2018). Infestations of armyworms can cause substantial damage to rice plants. Typically this damage is isolated to field edges, but in some cases large portions of fields can experience high levels of defoliation. Armyworms can infest rice at any point during the growing season. When infestations occur at early growth stages, it is common to see rice plants defoliated all the way to the soil line, or water level if the permanent flood is established. The current threshold for armyworms in rice is based on the number of larvae per square foot, which can be difficult to determine for growers and consultants. A defoliation threshold was developed in pure-line cultivars (Studebaker et al. 2023) but needs to be verified in hybrid cultivars. The objective of this study was to determine the impact of defoliation on hybrid rice yields compared to pure-line rice yields across multiple planting dates and growth stages.

Procedures

Studies were conducted at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center near Stuttgart, Ark., in 2022 to determine the impact defoliation has on rice across multiple planting dates. RT 7521 FP and Diamond were drill seeded at 22 and 70 lb/ac, respectively, on 8 April, 1 May, and 1 June. Plots were 8 rows (7.5-in. spacing) by 16.5 feet. Plots were defoliated to 100% using an electric weedeater at the 2–3 leaf, early tiller, late tiller, and green ring growth stages. Defoliations occurring at the 2–3 leaf growth stage were defoliated all the way to the soil line, but for all other growth stages plants were defoliated to the water line. Plots were arranged in a randomized complete block design with 7 replications within each planting date. Data were analyzed with PROC GLIMMIX SAS v. 9.4 (SAS Institute, Cary N.C.) with an alpha level of 0.05.

Results and Discussion

For the April planting, the hybrid cultivar incurred less yield loss than the pure-line cultivar across all defoliation timings (Fig. 1). Yield loss was observed for both cultivars at the two-three leaf, late tiller, and green ring growth stages, with the largest amount of yield loss occurring at the green ring growth stage. Higher yields were observed for the pure-line cultivar at the 2-3 leaf and green ring growth stages compared to the hybrid cultivar for the May planting (Fig. 2). At the June planting, no difference in yield loss was observed between the two cultivars at the two-three leaf or early tiller timing, however less yield loss was observed for the hybrid cultivar at the late tiller and green ring growth stage (Fig. 3).

Overall, trends suggest that defoliation threshold could potentially be increased for a hybrid cultivar compared to a conventional cultivar. While trends are similar to each other in most cases, this study needs to be replicated in the future to verify that different thresholds are needed.

Practical Applications

For now growers should use the current threshold in the MP144 for both conventional and hybrid rice, however with further research these recommendations may change.

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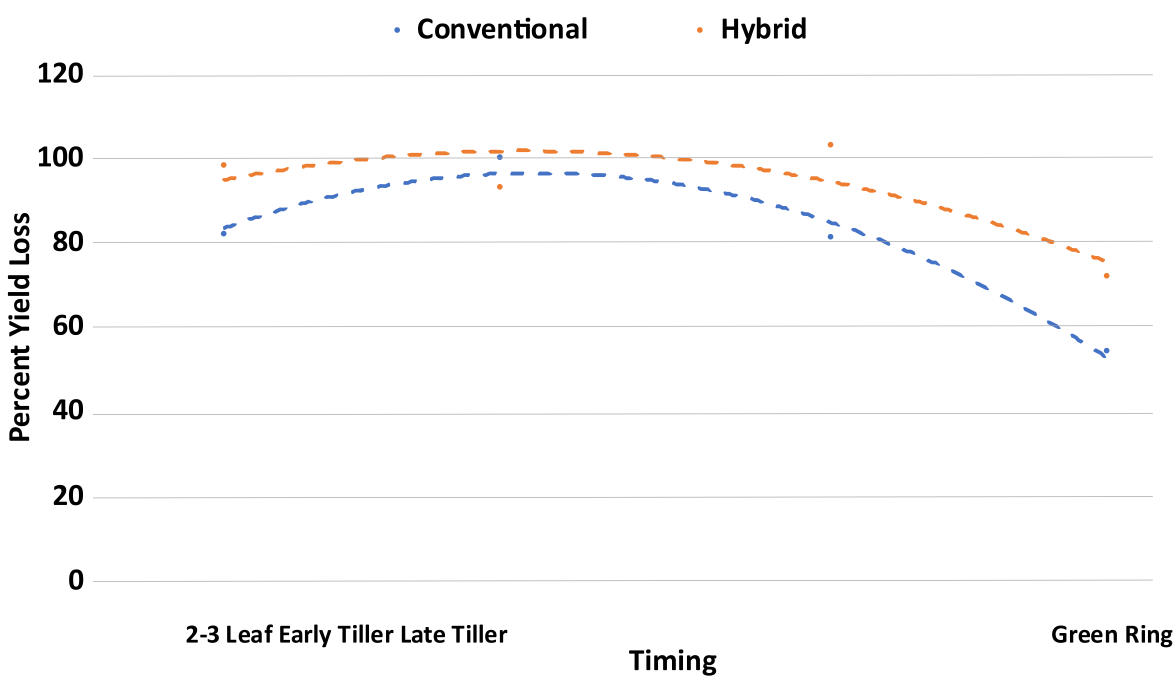

Fig. 1. Yield impacts caused by 100% of defoliation at varying growth stages in a conventional and hybrid cultivar for April planted rice in 2022.

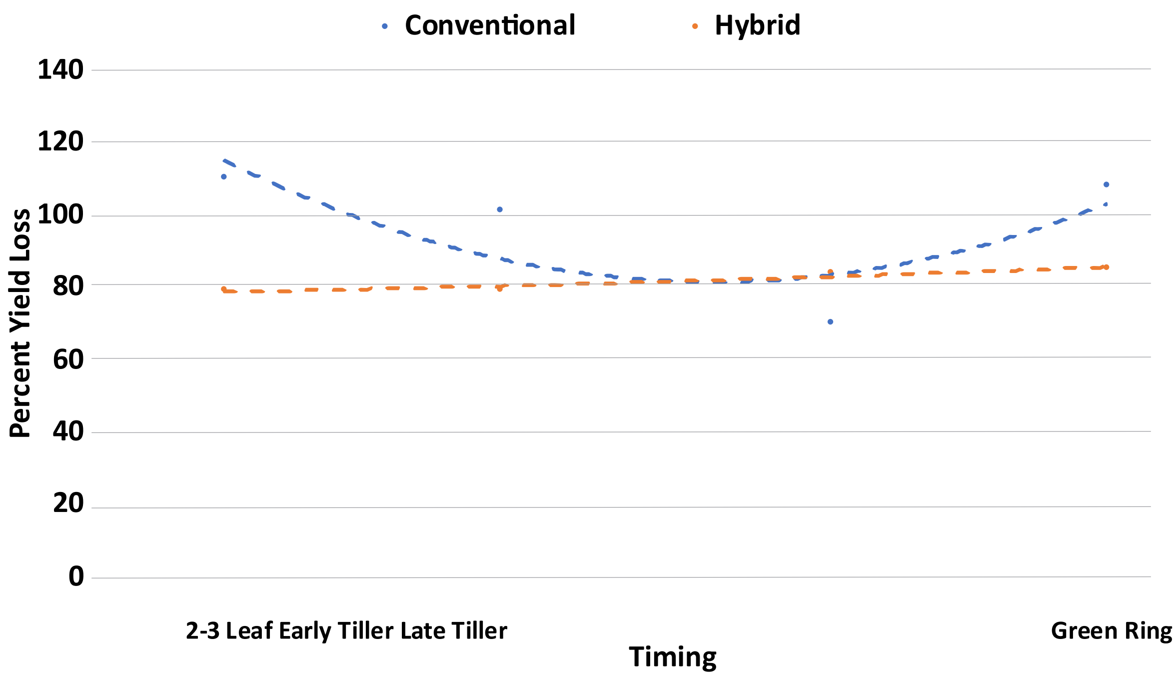

Fig. 2. Yield impacts caused by 100% of defoliation at varying growth stages in a conventional and hybrid cultivar for May planted rice in 2022.

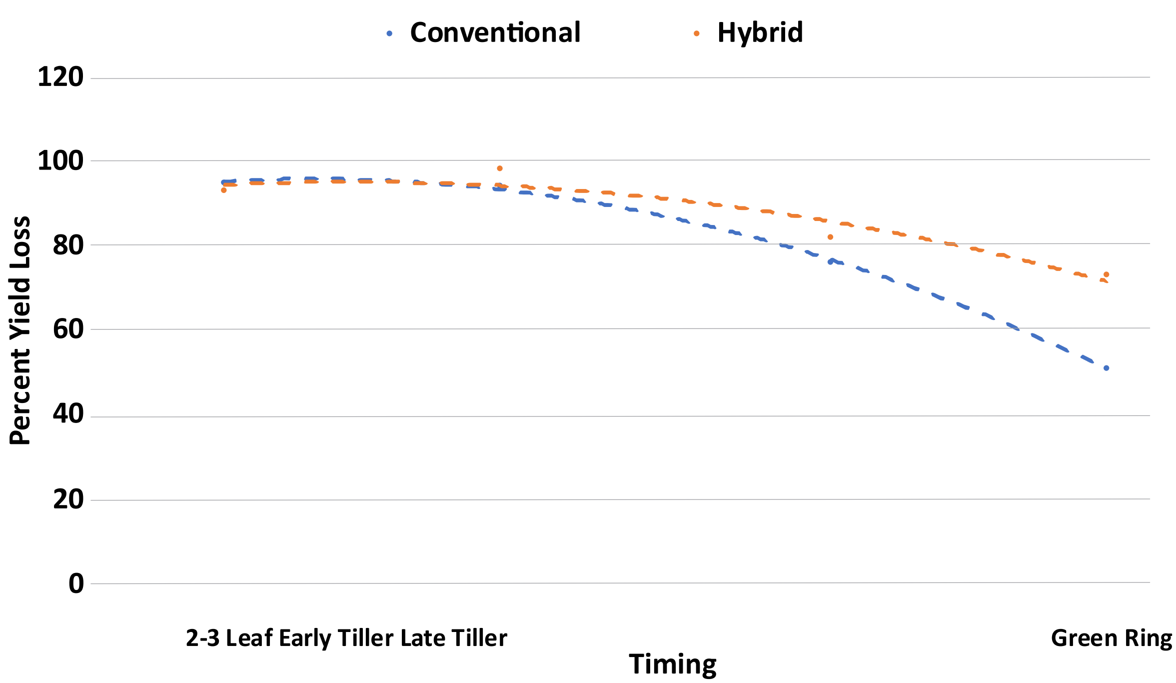

Fig. 3. Yield impacts caused by 100% of defoliation at varying growth stages in a conventional and hybrid cultivar for June planted rice in 2022.

Extraction and Evaluation of Rice Billbug (*Sphenophorus pertinax*) (Coleoptera: Curculionidae) Insect Lures Using Olfactory Techniques

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Abstract

The utilization of semiochemicals such as insect pheromones has proven successful in monitoring regimes for U.S. agriculture in the last half-century. The rice billbug, (*Sphenophorus pertinax*, Chittenden), has recently become a concern to mid-Southern U.S. rice producers implementing a potential cost-saving, production system. Furrow-irrigated rice hectare has continued to increase for the last five years. Lack of research on the rice billbug has raised concerns as the furrow-irrigated rice system gains popularity. Further understanding, and evaluations of control tactics have become a priority for entomologists in rice-growing regions of the U.S. Extraction and implementation of pheromone targeted for rice billbug, could allow timely control measures to take place and potentially reduce the amount of injured rice across the field. In this study, volatile semiochemicals extraction, and Y-tube choice tests were conducted at the University of Arkansas System Division of Agriculture's Department of Entomology in Fayetteville, Ark. Volatiles were extracted from rice billbug populations caught during the 2021 and 2022 growing season across the state of Arkansas. Three different chemicals (volatiles and closely related compounds) were evaluated for their attractancy to male and female rice billbugs. Findings from these preliminary studies show that a significant response to tested semiochemicals was observed. Blends A (4-Methyl-2-pentanol) and B (2,6-Dimethyl-4-heptanol) were more frequently selected compared to blend C containing tert-Butyl hydroperoxide. Blend C also suggested signs of repellency in males, and higher attraction in females. However, further research is needed in this direction as developing a semiochemical-based effective monitoring regime could potentially aid growers in economically and efficiently controlling rice billbug in future crops.

Introduction

In furrow-irrigated rice (FIR) rice billbug (*Sphenophorus pertinax*, Chittenden) (Coleoptera: Curculionidae) has achieved major pest status. Limited control measures have been observed to suppress rice billbug injury and retain yield. Findings from Floyd et al. (2021a) suggest that insecticide seed treatment combinations can suppress rice billbug populations and reduce injury. Findings from Floyd et al. (2021b) state that controlling rice billbug with a foliar application has not been successful. The authors suggest that application timing may be an issue in control failures with a foliar spray. The timing of rice billbug movement into the field has been refined in findings by Floyd et al. (2021c) but researchers suggest more investigation is warranted. In Arkansas, the implementation of pheromone in southwestern corn borer monitoring regimes allows growers and researchers to predict generations and target insecticide applications based on trap collection (McLeod and Studebaker, 2003). Researchers have hypothesized the utilization of rice billbug pheromone or related volatiles to target timely applications of foliar insecticides. If successful, the use of rice billbug semiochemicals could be a reliable source for FIR growers to make economically sound decisions on insecticide application. The objective of this experiment is to determine if some volatile compounds can be promoted into a rice billbug monitoring regime and deem development necessary.

Procedures

Initial Semiochemical Blend Testing

Sampling and Extraction. Rice billbug were collected from sites around Arkansas and placed in separate containers after being sexed in the field. Rice billbug were sexed using guidelines provided by findings of Chittenden (1905). The collected specimens were placed in a freezer to kill specimens before extractions. Once 400 billbugs of both male and female billbugs were collected the abdomen of both sexes were removed from head and thorax. The segments of the billbug were submerged in a glass vial containing a hexane solvent (5 ml) for 10 minutes, and then billbug segments were removed from the extract. Each sex had eight vials of both, head + thorax and abdomen solution. After extraction, all samples were filtered for any particles/insect body wax. These samples were analyzed using a matrix-assisted laser desorption/ionization (MALDI) mass spectrometry at the Arkansas Statewide Mass Spectrometry Facility. Volatile chemical compounds in samples were identified based on prominence. The three most prevalent compounds or related chemicals were evaluated for their attractancy to male and female rice billbugs.

Y-tube Bioassay. Behavioral assays were tested using a standard glass Y-tube to determine responses of rice billbug to volatile chemical compounds. In each arm of the Y-tube, a rubber septum loaded with 10 µl of the volatile compound (lure) was

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tested. Initial testing was conducted with no airflow being pushed through the Y tube. Rubber septum with volatile compound was placed in one trunk of the Y tube and untreated in the opposing trunk. Six rice billbug adults were placed at the trunk of the tube and sealed inside. Billbugs were placed in the tube for 10 min and first choice and residence time were noted. In this study, results were recorded in three categories: chose compound, chose control or did not choose. Each option was assigned a number for analysis. Three chemical compounds used in this study were (a): 4-Methyl-2-pentanol (Blend A), (b): 2,6-Dimethyl-4-heptanol (Blend B), and (c) tert-Butyl hydroperoxide (Blend C) (Table 1). These compounds were the most prevalent chemicals or similar to chemicals identified in the extraction process. These compounds were tested on both males and females separately. Six runs of this experiment were conducted for each compound and tested on both sexes of rice billbug. Individually, a male or female billbug was placed at the base of the trunk of the Y-tube. Billbugs were placed in the tube for 10 min and first choice and residence time were recorded. Each weevil was tested only one time and rubber septum lures were replaced after 6 runs. When transitioning from male to female testing, the olfactometer was cleaned thoroughly using an acetone solution to prevent any residual sensory chemicals for the opposing sex. The arm on which a chemical was placed in a previous run was changed to eliminate the risk of directional bias. A total of 36 billbugs, were tested at each run. Data were analyzed using the SAS v. 9.4. Initial runs of these experiments were analyzed using the PROC FREQ function, and significant responses to blends were tested using Fisher's exact test $\alpha = 0.05$.

Results and Discussion

Initial Semiochemical Blend Testing

Male Response. A total of 150 male billbugs were tested in these experiments. Frequency of response to selected semiochemical blends can be found in Table 2. A significant response to blends was observed in this study ($n = 150$; $df = 4$; $P < 0.01$). When analyzing the frequency of specimen that preferred the blend compared to the untreated check, blend A and B were most frequently selected at 40% and 42%, respectively. In contrast, blend C only had a 17.8% response by male billbugs. When analyzing solely blend, blend A, had a 37.5% response by male rice billbugs, while only 2.1% responded to the control. When testing blend B, male rice billbugs were more frequently making a choice compared to other blends. Blend B had a slightly higher frequency of response of 39.6% to the blend, but the control was selected more frequently (8.3%) when compared to blend A. Observations from the blend C experiment indicate that possible repellency was observed. The untreated control was twice as likely to be selected (35.2%) than blend C (14.8%). Regardless of blend, the most frequently recorded observation was male billbug did not choose. Over half of the billbugs tested for each chemical aggregated at the end of the y-tube and did not make a choice in the allotted time frame.

Female Response. A total of 90 female billbugs were tested in these experiments, and the frequency of response to selected semiochemical blends is stated on Table 3. A significant response to blends was observed in this study ($n = 90$; $df = 4$; $P < 0.01$). When analyzing response to blend A, 36.7% of females tested responded to the blend compared to the control (26.7%). However, blend B had slightly less response of 27.3% compared to the response from blend A. Blend B also had less of a response compared to its control. Blend C was more often selected by females (39.4%) than blends A or B. When testing females only 26.7% did not make a choice.

Pooled Response. Data from both the male and female experiments were pooled and a total of 240 billbug specimens were tested. A significant response to blends ($n = 240$; $df = 4$; $P < 0.01$) was also observed when combing the data sets (Table 4). When pooled, blend A was the most frequently selected (37.2%) compared to both blend B (35.9%) and C (26.9%) (Table 4). Independently, blend A was also more than twice as likely to be selected (37.9%) when compared to its control (11.5%). The untreated control was less frequently selected in the blend A runs (11.5%) compared to control selected in blends B (24.4%) and C (34.5%) Blend A also had the highest frequency of billbug specimens not making a choice (51.3%).

Practical Applications

Preliminary work on pheromones to be used in monitoring rice billbug shows some promise. With more refinement in both the pheromone and traps, a successful monitoring system can be established. Currently growers should evaluate their poly-plastic irrigation pipe as soon as rice begins to tiller and when it begins to senesce.

Acknowledgments

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Table 1. Description of chemical blends used in bioassay experiments.

Blend Title	Chemical
A	4-Methyl-2-pentanol
B	2,6-Dimethyl-4-heptanol
C	tert-Butyl hydroperoxide

Table 2. Frequency table for initial lures y-tube bioassays. Male rice billbug response to billbug lure blends.[a]

	Blend			
Response	**A**	**B**	**C**	**Total**
Did not Choose	29	25	27	81
Frequency	19.3	16.7	18.0	54.0
Row %	35.8	30.9	33.3	
Column %	60.4	52.1	50.0	
Chose Variable	18	19	8	45
Frequency	12.0	12.7	5.3	30.0
Row %	40.0	42.2	17.8	
Column %	37.5	39.6	14.8	
Chose Control	1	4	19	24
Frequency	0.7	2.7	12.7	16.0
Row %	4.2	16.7	79.2	
Column %	2.1	8.3	35.2	
N				150
df				4
$\boldsymbol{X^2}$				<0.01
P				<0.01

[a] Data was analyzed in PROC GLIMMIX using the Fisher's exact test at α = 0.05.

Table 3. Frequency table for initial lure y-tube bioassays. Female rice billbug response to billbug lure blends.[a]

	Blend			
Response	**A**	**B**	**C**	**Total**
Did not Choose	8	15	10	33
Frequency	8.9	16.7	11.1	36.7
Row %	24.2	45.5	30.3	
Column %	26.7	50.0	33.3	
Chose Variable	11	9	13	33
Frequency	12.2	10.0	14.4	36.7
Row %	33.3	27.3	39.4	
Column %	36.7	30.0	43.3	
Chose Control	11	6	7	24
Frequency	12.2	6.7	7.8	26.7
Row %	45.8	25.0	29.2	
Column %	36.7	30.0	23.3	
N				90
df				4
X^2				0.30
P				<0.01

[a] Data was analyzed in PROC GLIMMIX using the Fisher's exact test at α = 0.05.

Table 4. Frequency table for initial lure y-tube bioassays. Total rice billbug response to billbug lure blends.[a]

	Blend			
Response	**A**	**B**	**C**	**Total**
Did not Choose	40	31	34	105
Frequency	16.7	12.9	14.2	43.8
Row %	38.1	29.5	32.4	
Column %	51.3	39.7	40.5	
Chose Variable	29	28	21	78
Frequency	12.08	11.7	8.8	32.5
Row %	37.18	35.9	26.9	
Column %	37.18	35.9	25.0	
Chose Control	9	19	29	57
Frequency	3.75	7.9	12.1	23.8
Row %	15.79	33.3	50.9	
Column %	11.54	24.3	34.5	
N				240
df				4
X^2				<0.01
P				<0.01

[a] Data was analyzed in PROC GLIMMIX using the Fisher's exact test at α a= 0.05.

Evaluation of Insecticides and Application Methods in Furrow-irrigated Rice for Control of Rice Billbug [*Sphenophorus pertinax* (Chittenden)]

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Abstract

Experiments were conducted from 2020–2022 to evaluate effectiveness of insecticides and application methods for control of rice billbug. An insecticide seed treatment study was conducted using neonicotinoid and diamide insecticide seed treatments alone and in conjunction with one another to assess potential suppression of rice billbug injury. Additionally, a study was conducted to observe if foliar insecticide applications could suppress rice billbug. Multiple sampling methods were tested to correlate rice billbug damage to grain yield. At the panicle initiation growth stage, rice was sampled by counting total tillers and damaged tillers in five linear feet per plot. After panicle emergence, the number of blank heads per five linear feet within a plot was also recorded. Sampling rice prior to heading shows a general trend between treatments, but optimal timing needs to be evaluated. In the insecticide seed treatment study, a general trend was observed. Plots with a seed treatment containing a neonicotinoid in combination with a diamide product, resulted in yields greater than the untreated check or any single chemistry insecticide seed treatment. Rice seed treated with only a diamide resulted in greater yields when compared to a neonicotinoid treatment. Finally, no differences were observed when two neonicotinoids were applied to rice seed compared to a single neonicotinoid alone. All insecticide seed treatments significantly increased yield when compared to the untreated check. Results from the foliar insecticide study showed that greatest yields were observed with a combination seed treatment compared to any foliar insecticide applied regardless of timing.

Introduction

Furrow irrigated rice (FIR) acreage has been increasing in Arkansas over the past five years (Hardke and Chlapecka, 2019). In this production system, there is no standing water across the top third of the field, which has altered the pest complex for rice. Rice billbug (*Sphenophorus pertinax*), has commonly been considered a minor insect pest in the traditional flooded rice system, typically only feeding on rice found on the levee. Billbugs are restricted to the levee rice in these fields because they cannot survive in a flooded environment. Because FIR has changed irrigation practices, these fields are now susceptible to rice billbug injury. Prior to 2018, essentially no research had been conducted on rice billbug, due to its inability to infest rice planted in the traditional paddy system. Felts et al. (2019) found that combinations of neonicotinoids and diamide seed treatments resulted in higher yields than standalone insecticide seed treatments. Additionally, in scenarios where combination seed treatments weren't utilized, were foliar insecticides a viable option for rice billbug suppression. Developing best management practices for rice billbug in row rice is imperative as the popularity of this production system continues to increase.

Procedures

All experiments were conducted during the 2020, 2021, and 2022 growing seasons at nine site-years (location by year). Only four of the nine locations had signs of billbug injury and were used in the analysis. Plot sizes for all studies were 16 rows on 19 cm spacing by 5 m. Fertility, irrigation timings, and herbicide selection for all site-years were based on recommendations from the Arkansas Furrow-Irrigated Rice Handbook (Hardke and Chlapecka, 2019).

Data collection was the same for all experiments. Two sampling methods were evaluated to measure damage associated with rice billbug feeding. For the first sampling method, the total number of uninjured and rice billbug injured tillers was recorded for all plants in 1.5 meters of row per plot at 1.3 cm internode elongation. For the second sampling method, the total number of uninjured panicles and blank panicles were recorded for 1.5 meters of row per plot at the R9 growth stage. Once rice reached harvest maturity, one of the center two beds of each plot was harvested using a Wintersteiger (Wintersteiger AG, Austria) plot combine, equipped with a Harvest Master (Juniper Systems, Logan Utah) weight and moisture system. Rice yield was adjusted to 12% moisture content prior to statistical analysis.

All experiments were arranged as a randomized complete block with four replications. Statistical analysis was completed using the PROC GLIMMIX procedure in Statistical Analysis Software v. 9.4 (SAS Institute Inc., Cary, N.C.). Site-year and replication were treated as random effects. Data were pooled across all locations and years. Means were separated using Multiple Pairwise *t*-Tests at $\alpha = 0.05$ unless another procedure was specified.

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Insecticide Seed Treatment

All rice was treated with a base fungicide package consisting of sexdaxane, mefenoxam, azoxystrobin, and fludioxonil. Plot size was 16 rows on 7.5-in. spacing by 16.5 ft. Treatments consisted of single insecticide seed treatments and combinations of insecticide seed treatments. Treatments were arranged as a randomized complete block with four replications (Table 1).

Foliar Insecticide Study

To determine the efficacy and residual control of foliar insecticides, an experiment was conducted at a total of three locations, spanning across the growing seasons of 2020–2022 implementing a hybrid cultivar. A total of 15 treatments consisting of multiple foliar insecticides as well as insecticide seed treatments were arranged as a randomized complete block design with 4 replications. Three different foliar insecticides were evaluated in this study: lambda-cyhalothrin (Warrior II®, Syngenta Crop Protection AG, Basel, Switzerland), lambda-cyhalothrin + thiamethoxam (Endigo ZCX®, Syngenta Crop Protection AG, Basel, Switzerland), and chlorantraniliprole (Prevathon®, FMC Corporation, Philadelphia, Pa.) were independently applied at four timings. The foliar insecticide timings were at planting, 80% to 100% emergence, first tiller, and 4–5 tillers. Additionally, two insecticide seed treatment combinations and a fungicide-only seed treatment were evaluated as a comparison to the foliar insecticides. More information on the treatments evaluated is listed below (Table 2).

Results and Discussion

Overall, the utilization of insecticide seed treatments appears to be the most efficacious strategy for suppressing rice billbug populations (Table 3). Seed treatments containing diamide insecticides provided greater control than those only consisting of a neonicotinoid. This agrees with findings from Plummer et al. (2021) where insecticide seed treatment combinations provided the greatest control of rice water weevil. Increased control from the addition of a diamide was hypothesized to be due to both rice water weevil and rice billbug both belonging in the family *Curculionidae*. In Arkansas, where producers are faced with multiple major insect pests such as rice water weevil and grape colaspis, insecticide seed treatments are already implemented to control these pests. Findings from Plummer et al. (2021) suggest that combinations of multiple insecticide classes on seed have successfully controlled rice water weevil. Findings from this study show similar benefits for suppressing rice billbug. This indicates that producers who already implement combinations of insecticide seed treatment, will have to make no major adjustments if shifting to a FIR system. These data suggest that insecticide seed treatments should be recommended to suppress rice billbug populations and retain yield.

Foliar insecticide results show that more research needs to be conducted to discover the most efficacious application timing (Table 4). Currently, there is no clear timing that would optimize rice billbug control with a foliar application. A stipulation with foliar control of billbug is the limited number of insecticide options available for control. Results indicate that contact insecticides such as pyrethroids are not a viable option to control rice billbug. Findings from Floyd et al. (2022) indicate that rice billbugs are predominantly ground active. This could make contact insecticides less efficacious due to protection provided from the plant canopy. Systemic insecticides could result in better control, but limited options are available for use in rice. Results from these studies would suggest that foliar insecticides should not be the primary control tactic for suppressing rice billbug. Foliar insecticides may be considered as a secondary option, but more research is required before foliar applications can be recommended.

Practical Applications

The major takeaway from all the studies conducted from 2019 to 2022 is that rice billbug is the major insect pest of FIR. The one control tactic that performed better than all others was the use of a neonicotinoid seed treatment in conjunction with a diamide seed treatment. This combination performed better than foliar sprays, insecticide-coated urea, or single insecticide seed treatments. Even though combinations of insecticide seed treatments performed better yield-wise than all other treatments, damage still occurred in these plots. As of now there is no control method available to eliminate rice billbug injury. However, if growers are going to have FIR fields, they should be encouraged to use a combination of insecticide seed treatments.

Overall, findings from this research positively impact the FIR industry across the Mid-Southern U.S., with the goal of keeping FIR producers profitable. Though this research is pivotal, expansion of these findings is required. This research was conducted to be a foundation on which innovation and experimentation could be forged. As rice billbug awareness becomes more prominent, an increase in questions and concerns is inevitable. Further development of rice billbug management strategies is imperative to keep FIR producers profitable for years to come.

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Table 1. List of Insecticide Resistance Action Committee (IRAC) codes, active ingredient, trade name, and product rates for treatments included in rice billbug insecticide seed treatment studies conducted in Jackson County, Arkansas, from 2020 to 2022.

IRAC Code[†]	Active Ingredient	Trade Name	Rate
			(ml/100 kg seed)
4a	Thiamethoxam	CruiserMaxx Rice®	455
4a	Clothianidin	NipsIt Inside®	124
28	Chlorantraniliprole	Dermacor®	325
28	Cyantraniliprole	Fortenza®	226
4a + 4a	Thiamethoxam + Clothianidin	CruiserMaxx Rice® + NipsIt Inside®	455 + 124
4a + 28	Thiamethoxam + Chlorantraniliprole	CruiserMaxx Rice® + Dermacor®	455 + 325
4a + 28	Thiamethoxam + Cyantraniliprole	CruiserMaxx Rice® + Fortenza®	455 + 226
4a + 28	Clothianidin + Chlorantraniliprole	NipsIt Inside® + Dermacor®	124 + 325
4a + 28	Clothianidin + Cyantraniliprole	NipsIt Inside® + Fortenza®	124 + 326
N/A	Untreated	Untreated	N/A

[†] Denotes mode of action classification given by the Insecticide Resistance Action Committee.

Table 2. List of Insecticide Resistance Action Committee (IRAC) codes, active ingredient, trade name, application timings and product rates for treatments included in the rice billbug foliar insecticide studies conducted in Jackson County, Arkansas, from 2020 to 2022.

IRAC Code†	Active Ingredient	Trade Name	Timing	Rate
3a	Lambda-cyhalothrin	Warrior II®	at Planting‡	55 (ml/ha)
4a	Thiamethoxam Lambda-cyhalothrin	Endigo ZCX®	at Planting‡	148 (ml/ha)
28	Chlorantraniliprole	Prevathon®	at Planting‡	591 (ml/ha)
3a	Lambda-cyhalothrin	Warrior II®	80-100% Emergence§	55 (ml/ha)
4a 3a	Thiamethoxam Lambda-cyhalothrin	Endigo ZCX®	80-100% Emergence§	148 (ml/ha)
28	Chlorantraniliprole	Prevathon®	80-100% Emergence§	591 (ml/ha)
3a	Lambda-cyhalothrin	Warrior II®	1st Tiller¶	55 (ml/ha)
4a 3a	Thiamethoxam Lambda-cyhalothrin	Endigo ZCX®	1st Tiller¶	148 (ml/ha)
28	Chlorantraniliprole	Prevathon®	1st Tiller¶	591 (ml/ha)
3a	Lambda-cyhalothrin	Warrior II®	4-5th Tiller#	55 (ml/ha)
4a 3a	Thiamethoxam Lambda-cyhalothrin	Endigo ZCX®	4-5th Tiller#	148 (ml/ha)
28	Chlorantraniliprole	Prevathon®	4-5th Tiller#	591 (ml/ha)
4a 28	Thiamethoxam + Chlorantraniliprole	CruiserMaxx Rice® + Dermacor®	N/A	455 + 325 (ml/100 kg)
4a 28	Thiamethoxam + Cyantraniliprole	CruiserMaxx Rice® + Fortenza®	N/A	455 + 226 (ml/100 kg)
	N/A	Untreated	N/A	N/A

† Denotes Mode of action classification given by the Insecticide Resistance Action Committee.
‡ Denotes application dates were 14 May in 2021 and 14 May in 2022.
§ Denotes application dates were 24 May in 2021 and 20 May in 2022.
¶ Denotes application dates were 7 June in 2021 and 2 June in 2022.
# Denotes application dates were 16 June in 2021 and 27 June in 2022.

Table 3. Insecticide seed treatment control of rice billbug based on multiple sampling methods and grain yield for studies conducted in Jackson County, Arkansas, from 2020–2022.

Treatment Name	Total Tillers	Mean Tiller Injury	Tiller Injury	Mean Blank Heads	Blank Heads	Yield
			(%)		(%)	(kg/ha)
Thiamethoxam	7.8	2.0 ab[†]	18.4 abc	4.2	9.7	9219.7 b
Clothianidin	8.1	2.2 a	20.1 a	3.1	8.2	9218.7 b
Chlorantraniliprole	7.5	1.6 bdc	17.1 abc	2.9	7.6	9537.9b
Cyantraniliprole	7.1	1.5 d	15.2 c	3.3	8.2	9591.3 b
Thiamethoxam + Clothianidin	7.7	1.9 abc	17.1 abc	4.7	11.8	9232.8 b
Thiamethoxam + Chlorantraniliprole	7.5	2.0 ab	18.7 ab	3.7	8.6	10057.6 a
Thiamethoxam + Cyantraniliprole	7.4	1.9 abcd	17.9 abc	3.6	9.6	10116.6 a
Clothianidin + Chlorantraniliprole	7.4	1.6 dc	15.6 bc	3.6	8.4	9998.7 a
Clothianidin + Cyantraniliprole	7.7	1.5 dc	15.2 c	3.7	9.2	10079.8a
Untreated	7.7	2.01 ab	20.2 a	4.2	10.80	8426.7 c
df	9, 2164	9, 2164	9, 2164	9, 146	9, 146	27, 146
F	1.4	2.2	2.3	0.6	0.4	2.0
P	0.2	<0.01	0.01	0.8	0.9	<0.01

[†] Treatments with the same letter are not significantly different according to multiple Pairwise *t* test at $\alpha = 0.05$.

Table 4. Foliar insecticide control of rice billbug based on multiple sampling methods and grain yield for studies conducted in Jackson County, Arkansas, from 2020–2022.

Treatment Name	Application Timing	Total Tillers	Mean Tiller Injury	Tiller Injury	Mean Blank Heads	Blank Heads	Yield
				(%)		(%)	(kg/ha)
Lambda-cyhalothrin	at Planting	9.9	1.8	14.8	3.0	7.5	8872.9 bcd
Thiamethoxan Lambda-cyhalothrin	at Planting	8.9	1.4	12.1	3.2	8.0	8873.9 bcd
Chlorantraniliprole	at Planting	9.6	1.7	14.4	3.5	8.4	8870.8 bcd
Lambda-cyhalothrin	80-100% Emergence	10.4	1.7	13.9	3.3	7.8	8863.8 bcd
Thiamethoxan Lambda-cyhalothrin	80-100% Emergence	9.2	1.6	13.0	3.6	8.0	8840.6 bcd
Chlorantraniliprole	80-100% Emergence	10.4	2.0	18.4	3.4	8.4	8921.5 bc
Lambda-cyhalothrin	1st Tiller	9.7	1.5	13.2	3.3	7.9	8903.6 bc
Thiamethoxan Lambda-cyhalothrin	1st Tiller	9.4	1.2	10.9	3.5	8.0	8639.4 cde
Chlorantraniliprole	1st Tiller	10.2	1.4	11.2	3.6	10.7	9182.9 bc
Lambda-cyhalothrin	4-5th Tiller	9.8	1.3	10.8	3.1	7.9	8356.1 e
Thiamethoxan Lambda-cyhalothrin	4-5th Tiller	10.5	1.3	10.4	2.5	6.1	9106.3 bc
Chlorantraniliprole	4-5th Tiller	10.3	1.6	12.9	2.5	5.8	9406.7 b
Thiamethoxam Chlorantraniliprole	N/A	10.7	2.0	15.0	2.3	4.9	10309.2 a
Thiamethoxam Cyantraniliprole	N/A	10.3	1.8	15.2	3.3	7.8	10427.7 a
Untreated	N/A	9.9	1.6	12.2	4.0	9.6	8436.8 de
df		14, 104	14, 104	14, 104	14, 104	14, 104	14, 104
F		0.9	1.5	1.1	1.1	0.8	7.5
P		0.6	0.1	0.4	0.4	0.7	<0.01

† Treatments with the same letter are not significantly different according to multiple Pairwise *t* test at $\alpha = 0.05$.

Comparing Insecticide Seed Treatments and Insecticide Seed Treatment Combinations for Control of Rice Water Weevil

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Abstract

Grape colaspis (GC) and rice water weevil (RWW) are the most common and destructive insect pests of early-developing rice in the Southern US. The larvae of both pests are the main contributors of injury, feeding on the plant roots and leading to yield losses. The most common method of control for both pests is the use of insecticide seed treatments (IST). Foliar insecticide applications are also a control tactic for RWW but are not effective for grape colaspis. In 2022, research was conducted at two locations to compare ISTs and IST combinations for management of these pests on both conventional and hybrid rice cultivars. Further, varying rates of Dermacor were evaluated to determine if the rate could be reduced and still achieve adequate control while reducing the overall cost. All insecticide treatments provided greater control of RWW compared to the untreated check. Other than the hybrid cultivar at the Stuttgart location, no differences were observed among Deramcor rates. A general trend was observed that the higher rates of Dermacor had lower RWW densities compared to lesser rates. Results from this research suggest that reduced rates of Dermacor provide similar control to full rates which could potentially lower the cost of the overall seed treatment package.

Introduction

In Arkansas, there are multiple soil pests that affect rice plants. Of these pests, rice water weevil (*Lissorhoptrus oryzophilus*) and grape colaspis (*Colaspis brunnea*) are the most economically important (Lorenz et al., 2018). In Arkansas, 70–80% of the total rice acres utilize ISTs for RWW, GC, and other soilborne insect pest control. Previous research has proven that 80% of the time an IST treatment will improve stand counts and increase yields. (Taillon et al., 2016). Insecticide seed treatments provide higher efficacy and are more convenient than foliar insecticide applications as well (Taillon et al., 2014). The damaging life stage of both RWWs and GC is the larval stage. GC larvae feed on seedling rice before the permanent flood is applied, which will cause plant death and stand loss. RWW larvae will emerge after the flood is applied and feed on the roots of rice plants causing root pruning and in extreme cases plant death (Lorenz et al., 2018).

Insecticide seed treatments are the main control strategy implemented for both grape colaspis and rice water weevil (Thrash et al., 2020). Cruiser Maxx Rice (thiamethoxam) and NipsIt Inside (clothianidin) are neonicotinoids, and are the most efficacious seed treatments on grape colaspis. These insecticides are highly efficacious for a range of soil pests but are not dependable for RWW control compared to other treatments. The residual control for neonicotinoid seed treatments is only 28–35 days after planting. In common growing seasons, rice planted in April won't receive a permanent flood until 45–60 days following planting. By this point, neonicotinoids provide very little control of RWW.

On the other hand, diamide insecticide seed treatments such as, Dermacor X-100 (chlorantraniliprole) and Fortenza (cyantraniliprole) provide residual control up to 70–80 days after planting (Taillon et al., 2018). Previous research suggests that diamide seed treatments are more dependable than neonicotinoid treatments for RWW management, however they do not provide adequate control of grape colaspis. Studies have confirmed combinations of these insecticide classes improve overall soil pest control in rice (Bateman et al., 2022). Adoption of combining insecticide seed treatments has been slow due to the increased upfront cost. The objective of this study was to determine if rates of Dermacor could be reduced and still provide adequate control of rice water weevils with and without CruiserMaxx Rice to lower the upfront cost for rice producers.

Procedures

Small plot trials were conducted in 2022 at the University of Arkansas System Division of Agriculture's Pine Tree Research Station (PTRS) near Colt, Ark., and at the Rice Research and Extension Center (RREC) near Stuttgart, Ark. Experimental plot design was a randomized complete block with 4 replications and a plot size of 5 ft (8 rows) by 16.5 ft. RiceTec RT 7521FP and Horizon CLL16 were planted at PTRS on 10 May and at RREC on 12 April at 20 lb/ac, and 60 lb/ac, respectively. Treatments included a fungicide

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only (untreated control), Cruiser Maxx rice, and multiple rates of Dermacor X-100 (Table 1).

The RWW larvae were evaluated by taking 3 core samples per plot with a 4-in. core sampler approximately 21 days after permanent flood establishment. Samples were evaluated at the Lonoke Agricultural Extension and Research Center in Lonoke, Ark. Each core was washed into a 40-mesh sieve with water to loosen soil and remove larvae from the roots. The sieve was immersed in a warm saturated saltwater solution which caused the larvae to float for counting. 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

All insecticide seed treatments reduced RWW densities below that of the untreated control on the conventional cultivar (Horizon CLL16) at the PTRS location (Fig. 1). The Dermacor 0.25x rate had more RWW larvae present compared to the Dermacor 0.5x rate. No other differences were observed among the other treatments. All insecticide seed treatments reduced RWW population densities below that of the untreated control on the hybrid rice variety (RiceTec RT 7521FP) at the PTRS location (Fig. 2). The CMR plus Dermacor 0.75x rate had the lowest RWW population density when compared to Dermacor at 0.25x rate. No other differences between insecticide treatments were observed. At the RREC location, all insecticide seed treatments on the conventional rice cultivar reduced RWW populations when compared to the untreated control (Fig. 3). Dermacor at rates of 1x and 0.75x, as well as CMR plus Dermacor 1x rate provided greater control than CMR and CMR plus Dermacor 0.25x rate. No other differences in insecticide seed treatments were observed. All insecticide seed treatments on the hybrid cultivar at the RREC location reduced RWW populations when compared to the untreated check (Fig. 4). All insecticide seed treatments other than Dermacor 0.25x rate and CMR plus Dermacor 0.25x rate showed greater control of RWW than CMR. CMR and Dermacor 0.25x rate had more RWW larvae present at the time of sampling than Dermacor 0.5x rate and CMR plus Dermacor 1x rate. No other differences between treatments were observed.

Overall, diamide seed treatments alone or in combination with a neonicotinoid seed treatment reduced rice water weevil densities compared to untreated rice. This data supports growers incorporating diamide seed treatments in their production practices. While grape colaspis was not present in these studies, they still cause significant damage in rice without a neonicotinoid seed treatment on a yearly basis. This data suggests that reduced rates of Dermacor will still provide adequate control of RWW, however an overall trend of more RWW larvae being present in reduced rates of Dermacor compared to full rates was observed.

Practical Applications

In areas where RWW as well as other soil insect pests are a concern, combinations of neonicotinoid and diamide seed treatments are recommended. Growers could potentially reduce upfront costs by reducing the rate of Dermacor, but more work needs to be done to determine how this will affect resistance management.

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Table 1. A list of insecticide seed treatment, rate, and class for cultivars used in rice water weevil studies conducted at the University of Arkansas System Division of Agriculture's Pine Tree Research Station near Colt, Ark., and at the Rice Research and Extension Center near Stuttgart, Ark., in 2022.

	Rate		
	Cultivar Type		
Insecticide Seed Treatment	**Hybrid**	**Conventional**	**Insecticide Class**
Untreated Check			
Dermacor X-100 (1x)	5 oz/cwt	2.5 oz/cwt	Diamide
Dermacor X-100 (0.75x)	3.75 oz/cwt	1.88 oz/cwt	
Dermacor X-100 (0.5x)	2.5 oz/cwt	1.25 oz/cwt	
Dermacor X-100 (0.25x)	1.25 oz/cwt	0.63 oz/cwt	
CruiserMaxx Rice	7 oz/cwt	7 oz/cwt	Neonicotinoid
CruiserMaxx Rice +	7oz/cwt +	7oz/cwt +	Neonicotinoid + Diamide
Dermacor X-100 (1x)	5 oz/cwt	2.5 oz/cwt	
CruiserMaxx Rice +	7oz/cwt +	7oz/cwt +	
Dermacor X-100 (0.75x)	3.75 oz/cwt	1.88 oz/cwt	
CruiserMaxx Rice +	7oz/cwt +	7oz/cwt +	
Dermacor X-100 (0.5x)	2.5 oz/cwt	1.25 oz/cwt	
CruiserMaxx Rice +	7oz/cwt +	7oz/cwt +	
Dermacor X-100 (0.25x)	1.25 oz/cwt	0.63 oz/cwt	

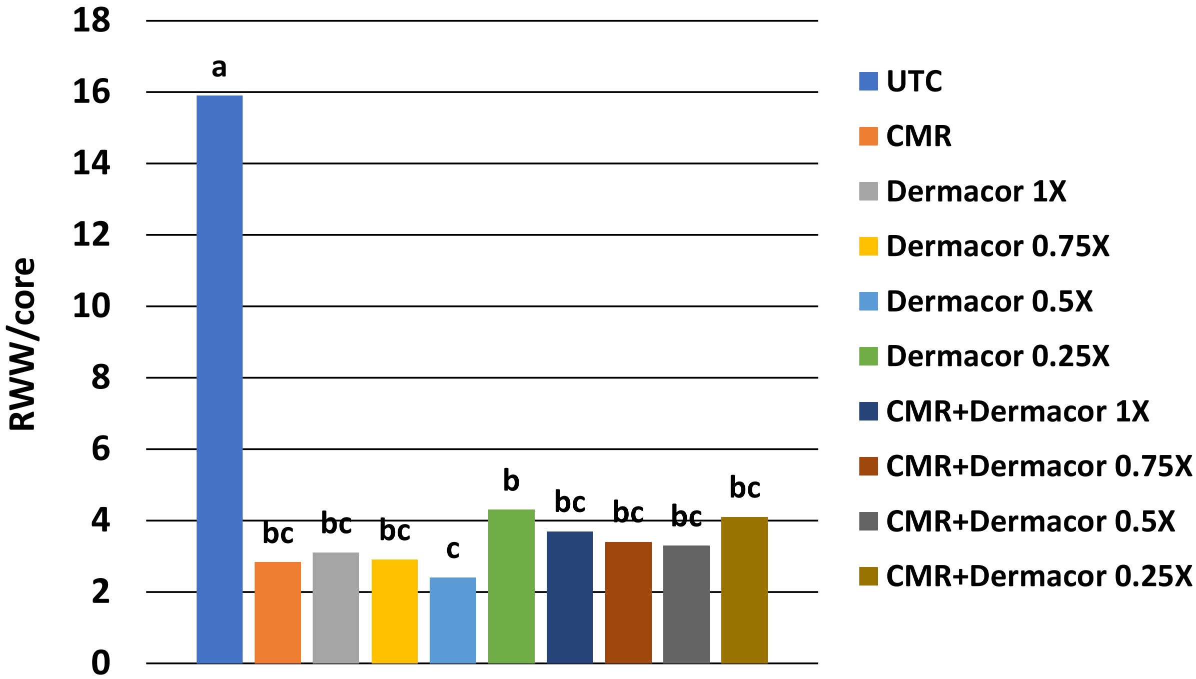

Fig. 1. Rice water weevil control comparing multiple rates of Dermacor with and without CruiserMaxx Rice to the untreated check in conventional rice at the University of Arkansas System Division of Agriculture's Pine Tree Research Station, near Colt, Ark., in 2022. Treatments with the same letter are not different according to Duncan's numerical range test at α = 0.05.

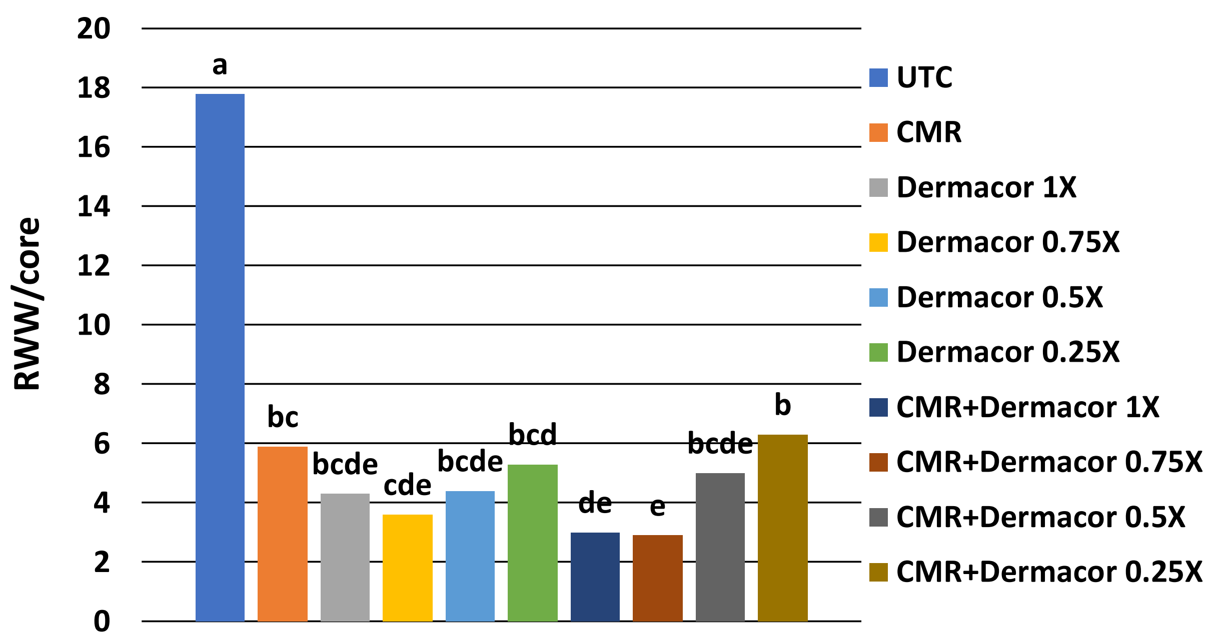

Fig. 2. Rice water weevil control comparing multiple rates of Dermacor with and without CruiserMaxx Rice to the untreated check in hybrid rice at the University of Arkansas System Division of Agriculture's Pine Tree Research Station, near Colt, Ark., in 2022. Treatments with the same letter are not different according to Duncan's numerical range test at α = 0.05.

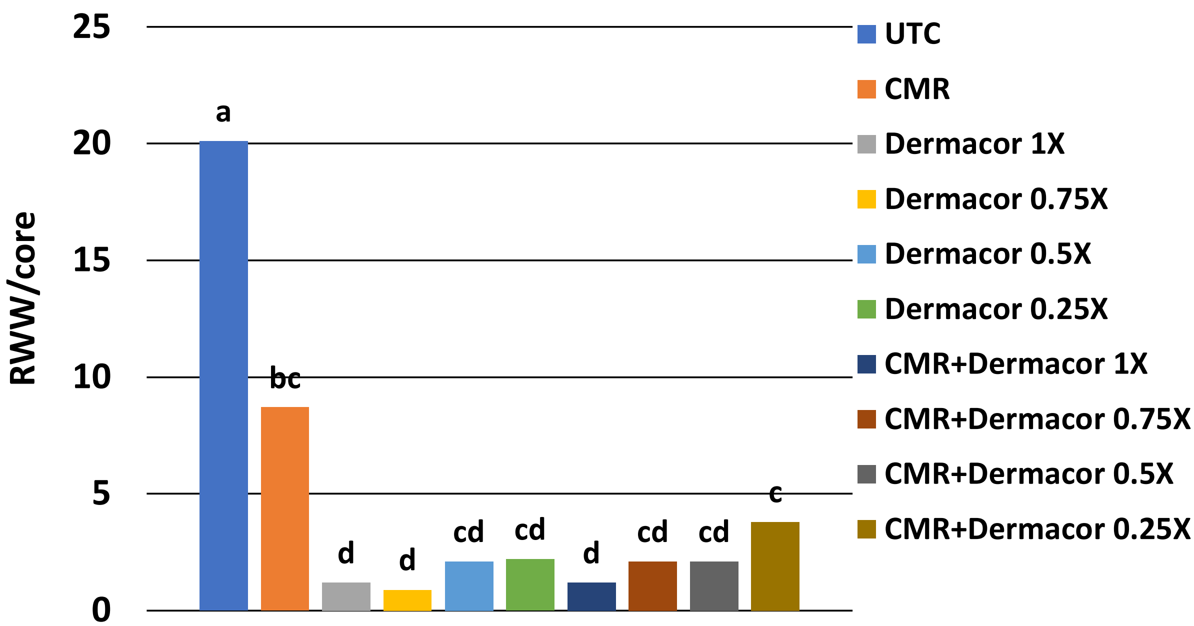

Fig. 3. Rice water weevil control comparing multiple rates of Dermacor with and without CruiserMaxx Rice to the untreated check in conventional rice at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center, near Stuttgart, Ark., in 2022. Treatments with the same letter are not different according to Duncan's numerical range test at $\alpha = 0.05$.

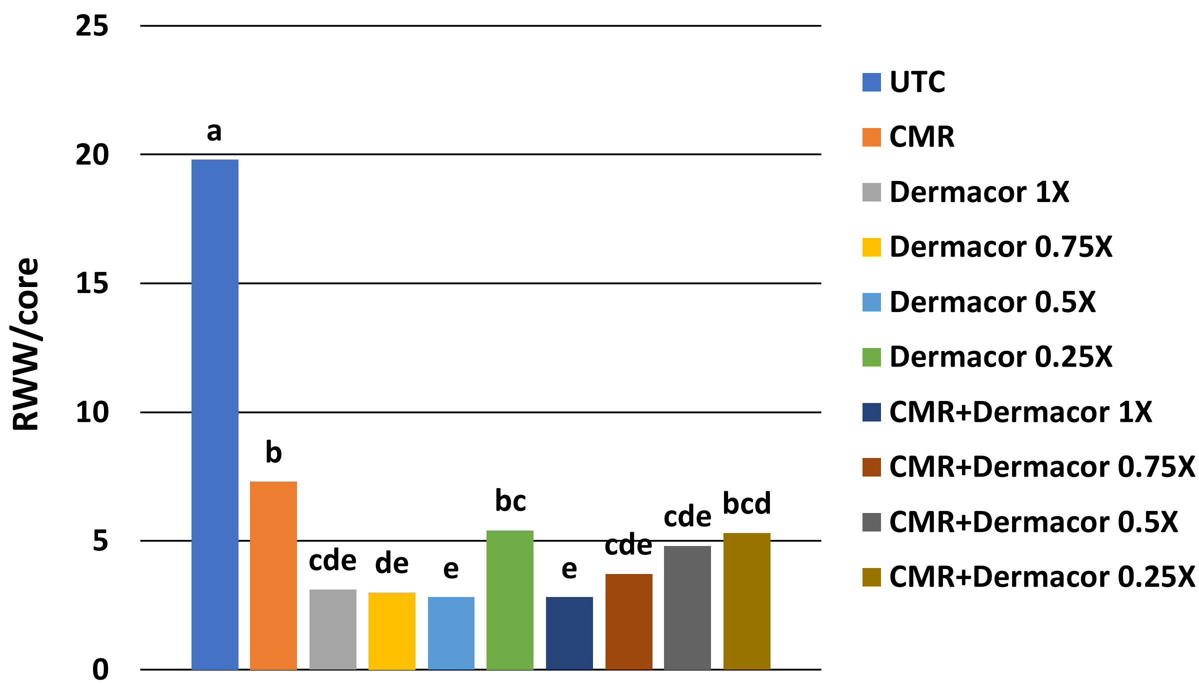

Fig. 4. Rice water weevil control comparing multiple rates of Dermacor with and without CruiserMaxx Rice to the untreated check in hybrid rice at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center, near Stuttgart, Ark., in 2022. Treatments with the same letter are not different according to Duncan's numerical range test at $\alpha = 0.05$.

Comparison of Multiple Insecticides for Efficacy and Residual Control of Rice Stink Bug in Arkansas, 2022

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Abstract

Rice stink bug (RSB) is a major pest of rice, feeding on developing grain, which can lead to yield and quality losses. Few insecticides are currently available to rice producers for rice stink bug management. Lambda-cyhalothrin (lambda) is the most common insecticide used to manage RSB due to its low cost. Over 50% of Arkansas rice acreage is treated with lambda for control of RSB annually. Other options, such as Tenchu (dinotefuran), are effective for control but not at a competitive price point. The dependency on lambda for RSB control, and control issues observed in Louisiana and Texas, raises concern for RSB resistance in Arkansas. New options for RSB need to be evaluated to determine effective alternatives to lambda. Foliar efficacy field trials were performed in 2021 and 2022 to compare insecticides for efficacy and residual control of rice stink bug. Sweep net samples were taken at 3, 7, 10, and 14 days after treatment (DAT) to monitor RSB efficacy. Excluding the pyrethroids, all other insecticides provided adequate control of RSB at 3 and 7 DAT. Only Tenchu and Endigo ZCX provided adequate control of RSB at 10 and 14 DAT.

Introduction

Rice stink bug (RSB), *Oebalus pugnax* F., is a major pest of rice in Arkansas. The RSB can cause yield loss if feeding occurs during the flowering and milk growth stages, or quality loss if feeding occurs during the soft or hard dough growth stages (Swanson and Newsom, 1962). Growers in Arkansas average one insecticide application per year to manage for RSB. However, multiple applications may be warranted to keep RSB densities below threshold in very early or very late heading rice. Thresholds for RSB in Arkansas during weeks 1 and 2 after 75% heading is 5 RSB per 10 sweeps, and 10 RSB per 10 sweeps during weeks 3 and 4 after 75% heading.

Limited insecticide options are currently available for RSB control (Lorenz et al., 2018). Lambda-cyhalothrin (Warrior II and generics), a pyrethroid, has been the standard for RSB control for the past 15 years. In contrary to findings of Way and Tindall (2009), products are now available with longer residual than pyrethroid products such as Tenchu, but it is considerably more expensive ($12/ac) than lambda ($2/ac). Concerns with resistance due to the lack of chemistry rotation are still a possible threat to mid-southern U.S. rice producers. The objective of this study was to compare the efficacy and residual control of insecticides for control of RSB.

Procedures

Foliar efficacy trials were conducted in 2021 and 2022 to compare multiple insecticides for efficacy and residual for RSB control. Locations were selected when RSB densities exceeded threshold. Applications of insecticides were made with a backpack sprayer and a 12 ft hand boom calibrated to 10 GPA at 2.5 MPH using TeeJet flat fan nozzles. Treatments were arranged in a randomized complete block design with four replications and a plot size of 12 ft by 35 ft (Table 1). Sweep net sampling was performed at 3, 7, 10, and 14 days after treatment (DAT), by conducting 1 set of 10 sweeps per plot to monitor RSB populations. Sampling was conducted until plots reached 60% hard dough.

Results and Discussion

At 3 DAT, Endigo ZCX (both rates) Tenchu, Carbaryl, and Malathion provided better control of total RSB than Lambda Cy or Mustang Maxx (Fig. 1). However, only Tenchu and Endigo ZCX (both rates), and Carbaryl provided better control of RSB nymphs than Lambda Cy. Tenchu and both rates of Endigo ZCX also performed better on RSB nymphs than Mustang Maxx. At 7 DAT, Carbaryl, Tenchu, and Endigo ZCX (both rates) had greater control of total RSB populations, compared to Mustang Maxx and Lambda Cy. Lambda Cy had greater control of nymphs than Mustang Maxx. However, Lambda Cy had less nymphal control than Tenchu and Endigo ZCX (both rates) (Fig. 2). At 10 DAT, Carbaryl, Tenchu, and Endigo ZCX (both rates) provided substantial control of RSB nymphs, compared to Lambda Cy and Malathion (Fig. 3). At 14 DAT, Tenchu and Endigo ZCX (both rates) provided greater control of nymphs than all other insecticides. Carbaryl controlled RSB nymphs more than Lambda Cy, Mustang Maxx, and Malathion (Fig. 4).

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Efficacy studies focused on nymph numbers rather than adult numbers, due to plot sizes being relatively small, and the rest of the field not receiving an insecticide treatment. Adult RSBs migrate from field to field, therefore, selecting RSB nymphs is the most appropriate indicator for insecticide efficacy. Nymphs also continuously feed on rice plants, due to their inability to take flight and enter surrounding fields. Adults and nymph RSB are damaging to rice, in sampling combining numbers is a common practice, hence the reasoning for the total being represented in the data charts.

Practical Applications

Arkansas rice producers have limited products in their arsenal for RSB control. Applications of lambda should still be considered but growers should also be prepared to change if adequate control isn't achieved. If rice stink bug nymphs are found after Lambda applications, rotating to either Tenchu or Malathion is recommended. With the growing concerns of pyrethroid resistance/tolerance of RSB, new insecticide options should be evaluated. New products such as Endigo ZCX (label pending) could potentially aid growers in RSB control.

Acknowledgments

The authors would like to express their appreciation to the Arkansas Rice Checkoff Program administered by the Arkansas Rice Research and Promotion Board, the University of Arkansas System Division of Agriculture, and all the cooperators that allowed us use of their land.

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Table 1. Insecticide names, rates, and insecticide class included foliar rice stink bug efficacy studies conducted throughout Arkansas in 2021 and 2022.

Insecticide Name	Rate (oz/ac)	Active Ingredient	Insecticide Class
Lambda-Cy	3.65	Lambda-cyhalothrin	Pyrethroid
Mustang Maxx	4	Zeta-cypermethrin	Pyrethroid
Tenchu	8	Dinotefuran	Neonicotinoid
Carbaryl 4L	32	Bifenthrin	Carbamate
Malathion 57	32	Malathion	Organophosphate
Endigo ZCX	5-6	Thiamethoxan + Lambda-cyhalothrin	Neonicotinoid + Pyrethroid

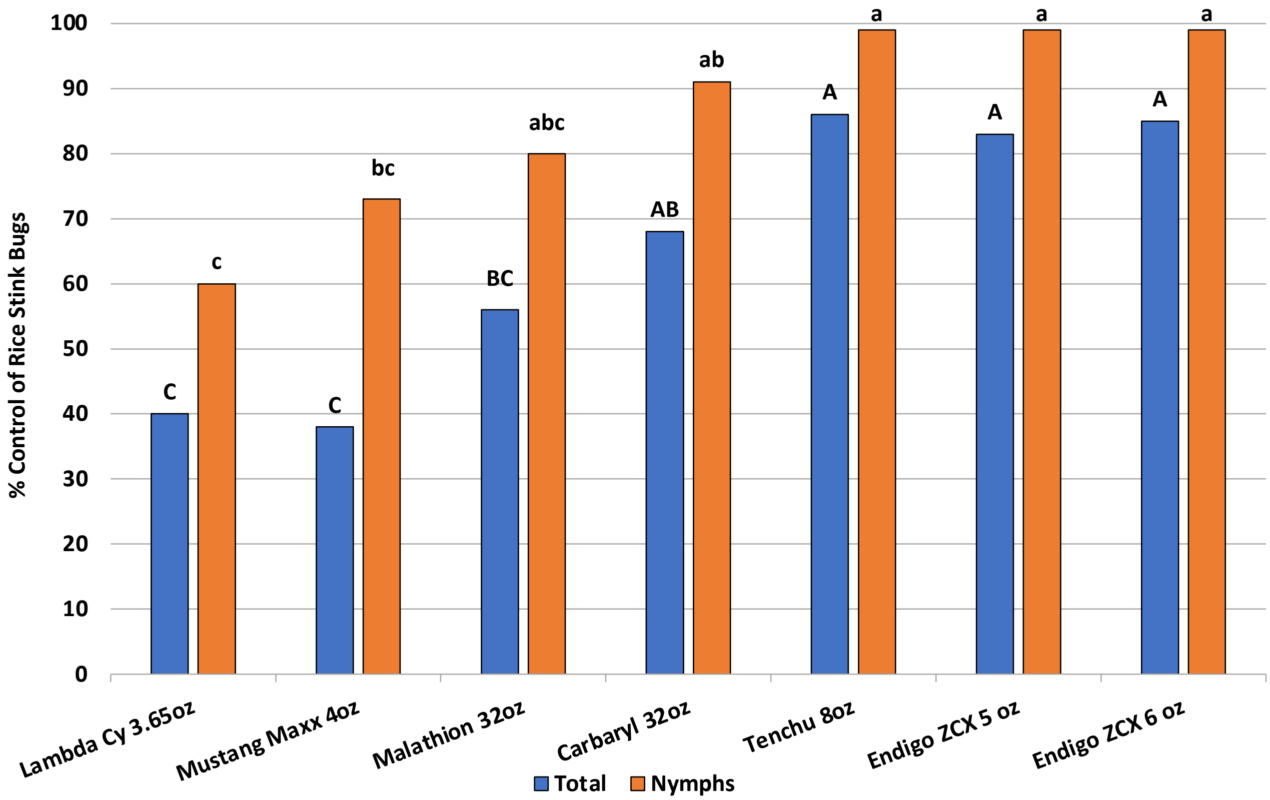

Fig. 1. Average percent control of rice stink bugs 3 days after treatment for efficacy studies conducted in 2021 and 2022 at multiple locations throughout Arkansas. Treatments with the same letter are not different according to Duncan's numerical range test at α = 0.05.

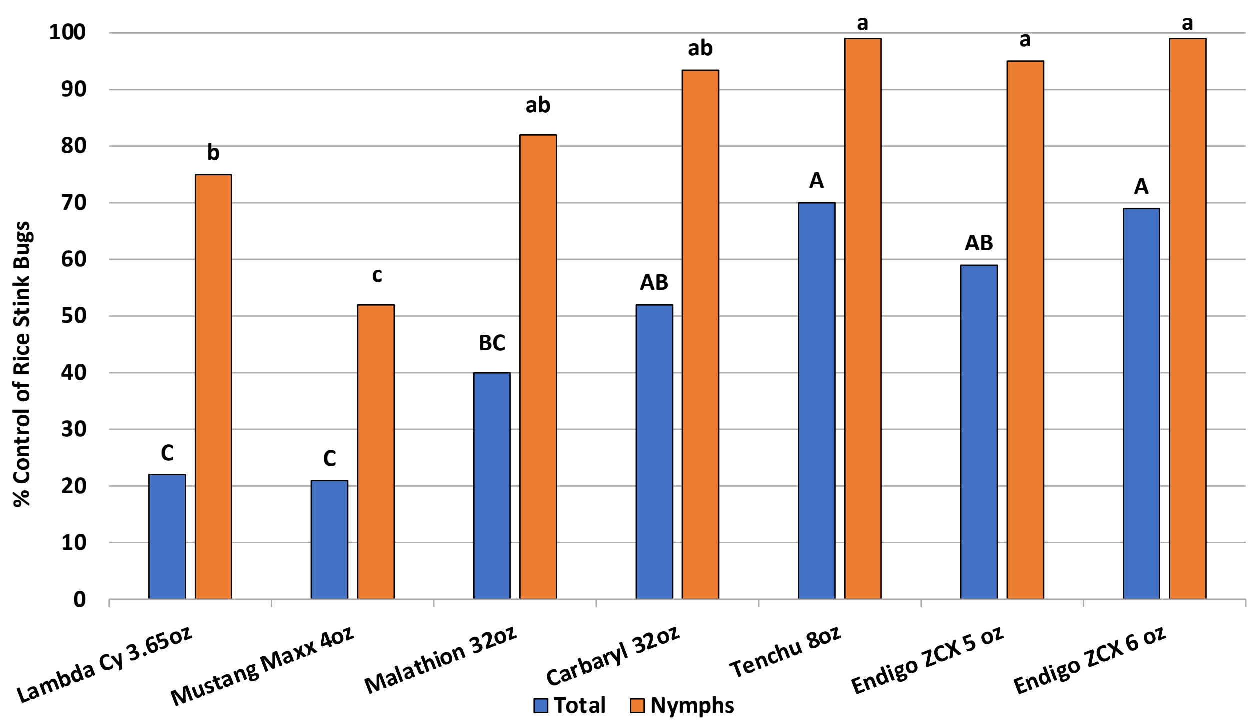

Fig. 2. Average percent control of rice stink bugs 7 days after treatment for efficacy studies conducted in 2021 and 2022 at multiple locations throughout Arkansas. Treatments with the same letter are not different according to Duncan's numerical range test at α = 0.05.

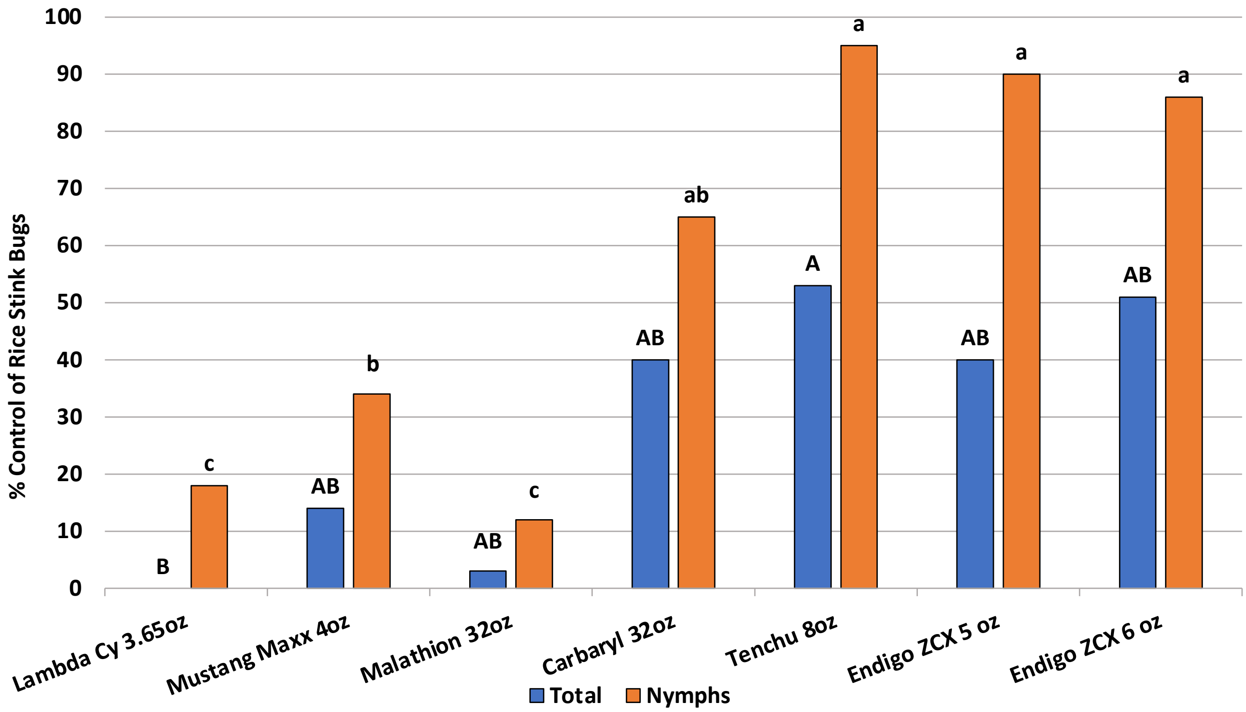

Fig. 3. Average percent control of rice stink bugs 10 days after treatment for efficacy studies conducted in 2021 and 2022 at multiple locations throughout Arkansas. Treatments with the same letter are not different according to Duncan's numerical range test at α = 0.05.

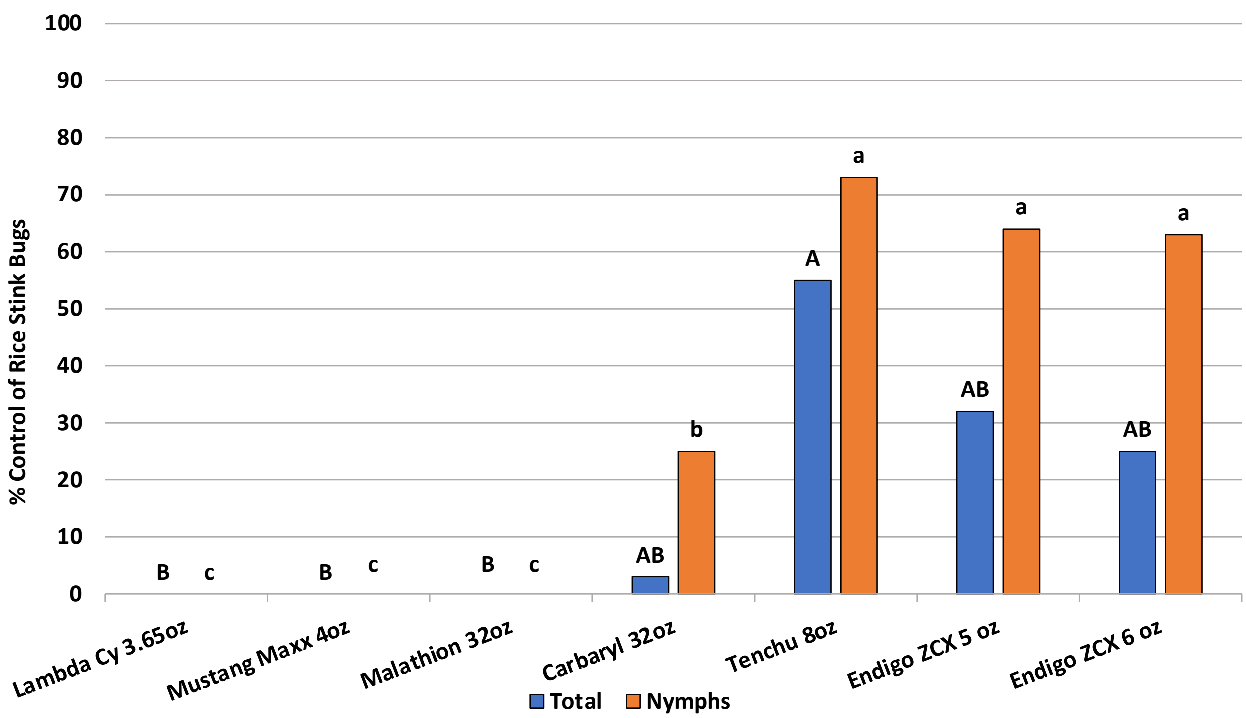

Fig. 4. Average percent control of rice stink bugs 14 days after treatment for efficacy studies conducted in 2021 and 2022 at multiple locations throughout Arkansas. Treatments with the same letter are not different according to Duncan's numerical range test at α = 0.05.

Examining Probable Pyrethroid Failures in Arkansas Rice Stink Bug Populations

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Abstract

Rice stink bugs (RSB) are a major pest of rice after panicle emergence in Arkansas. Pyrethroids, particularly lambda-cyhalothrin (lambda), have been the primary insecticide used to control RSB for the past 15 years. Recently, there have been increasing concerns of potential pyrethroid resistance. Lambda control failures have been documented in Arkansas in late-season RSB populations since 2019. Populations of RSB's were collected in May, June, July, and August throughout the state in 2021 and 2022. Lambda was applied to petri dishes at multiple rates to determine the efficacy of RSB. Fifty-four collections were made throughout 2021 and 2022. Over the fifty-four populations that were sampled, percent mortality ranged from 66% to 68% between the 1x and 4x rates of lambda. Slightly higher mortality was observed in May as compared to the other months collections were made. These preliminary results indicate that pyrethroid insecticide resistance may become an increasing problem in Arkansas, and future management strategies need to be evaluated.

Introduction

The rice stink bug (RSB), *Oebalus pugnax* F., is the number one pest of heading rice in Arkansas. In recent growing seasons, approximately 50% of rice acres were treated for control of RSB. Estimates suggest RSB is costing producers $18.29/ac in losses + costs across the mid-South (Bateman et al., 2017). Rice stink bug can cause yield loss during the flowering and milk stages and quality losses (pecky rice) during the soft dough and hard dough growth stages. Peck typically appears as circular spots or "bullseye shaped lesions" on rice kernels, associated with RSB feeding. Peck causes shrunken kernels and increases kernel breakage during the milling process.

Traditionally over the past 20 years, pyrethroids made up over 99% of all applications targeting RSB in Arkansas. Lambda-cyhalothrin (Warrior II, Silencer, LambdaCy, Kendo, Lambda Star, etc.) is the most used pyrethroid for RSB control. Other pyrethroids such as, zeta-cypermethrin (Mustang Maxx) and gamma-cyhalothrin (Declare or Prolex) are labeled for RSB control but are rarely used due to the cost-effectiveness and availability of lambda-cyhalothrin. A neonicotinoid, dinotefuran (Tenchu), is labeled but the cost is much higher than the pyrethroids, and it has not been widely adopted by growers (EPA Reg. No. 33657-17 et al., 2009). Rice stink bug resistance to pyrethroids has not been documented in Arkansas, however, there have been reported problems with resistance in Texas (Miller et al., 2010; Blackman et al., 2015). However, multiple control failures were reported in 2019 and 2020 late in the growing season (Lorenz et al., 2020; Newkirk et al., 2021). The objective of this study was to determine if there is a developing problem with pyrethroid insecticide resistance to rice stink bug in Arkansas.

Procedures

Bioassays were performed throughout 2021 and 2022 to determine the mortality of RSB to lambda. Rice stink bugs were collected over a total of 54 locations throughout Arkansas. Collections were made throughout the growing season, starting in May, and ending in August. Approximately 450 RSB were collected from each location. Collections were made with sweep nets in rice fields, wheat fields, and native grasses. RSBs were transferred to rearing cages and held overnight at 72 °F, to ensure healthy RSBs were used for infestation. Plants were placed in rearing cages for feeding and cotton balls soaked in sugar water for moisture. Rice stink bugs were transported to the laboratory at the University of Arkansas System Division of Agriculture's Stuttgart Rice Research and Extension Center, Stuttgart, Arkansas to conduct assays.

(Warrior II was applied to 4-in. petri dishes at five different rates: 0.46 oz/ac (0.25X), 0.93 oz/ac (0.5X), 1.86 oz/ac (1.0X), 3.72 oz/ac (2.0X), and 7.44 oz/ac (4.0X) and an untreated check for comparison. Lambda was applied to petri dishes with a backpack sprayer, using a 2-row hand boom, with TeeJet hollow cone tips calibrated to 10 GPA at 4 MPH. Each treatment was replicated ten times. Petri dishes were allowed to dry before inserting five RSB adults in each dish. Mortality was recorded 24 hours after infestation.

Results and Discussion

In May, the 1X, 2X, and 4X rates had higher mortality than the 0.25X and 0.5X rates. No differences were observed between the 1X, 2X, and 4X rates of lambda for mortality of RSB (Fig.

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1). In June, no rate achieved 70% mortality, however differences were observed between rates. The 1X, 2X, and 4X rates had higher mortality than the 0.25X and 0.5X rates. Additionally, the 4x rate had higher mortality than the 1x rate but was not different from the 2x rate (Fig. 2). In July, the 1X, 2X, and 4X rates had higher mortality than the 0.25X and 0.5X rates (Fig. 3). No differences were observed among the 1x, 2x, and 4x rate. For the month of August, the 2X rate had lower mortality compared to the 1X and 4X (Fig. 4). Across all months, all treatments had increased mortality compared to the untreated check (Fig. 5). The 4x rate had higher mortality than all other rates of lambda. The 1x and 2x rates had higher mortality than the 0.25x and 0.5x rates, but no difference was observed between the 1x and 2x rates.

Overall lambda was not able to achieve adequate control (≤80%) at any rate or within any month. A general trend was observed that less mortality was observed as months progressed, however this was nominal at best. May populations are the first generation of RSB coming out of overwintering, which are generally weaker than June, July, and August populations. Based on these data, growers should not expect greater than 70% control with lambda, and most likely much worse as the season progresses.

Practical Applications

Assay results indicate that resistance/tolerance of rice stink bugs to Lambda may be a developing issue for Arkansas rice producers. If pyrethroid resistance is developing, we will need to educate our growers and consultants on sustainable insecticide resistance management. Future research will continue to be conducted to monitor resistant populations and to develop management plans to help combat RSB going forward.

Acknowledgments

The authors wish to express appreciation to Arkansas crop consultants and county agents for identifying problem fields. We also express our appreciation for funding and support from the Arkansas rice growers administered through the Rice Research and Promotion Board. Support was also given by the University of Arkansas System Division of Agriculture.

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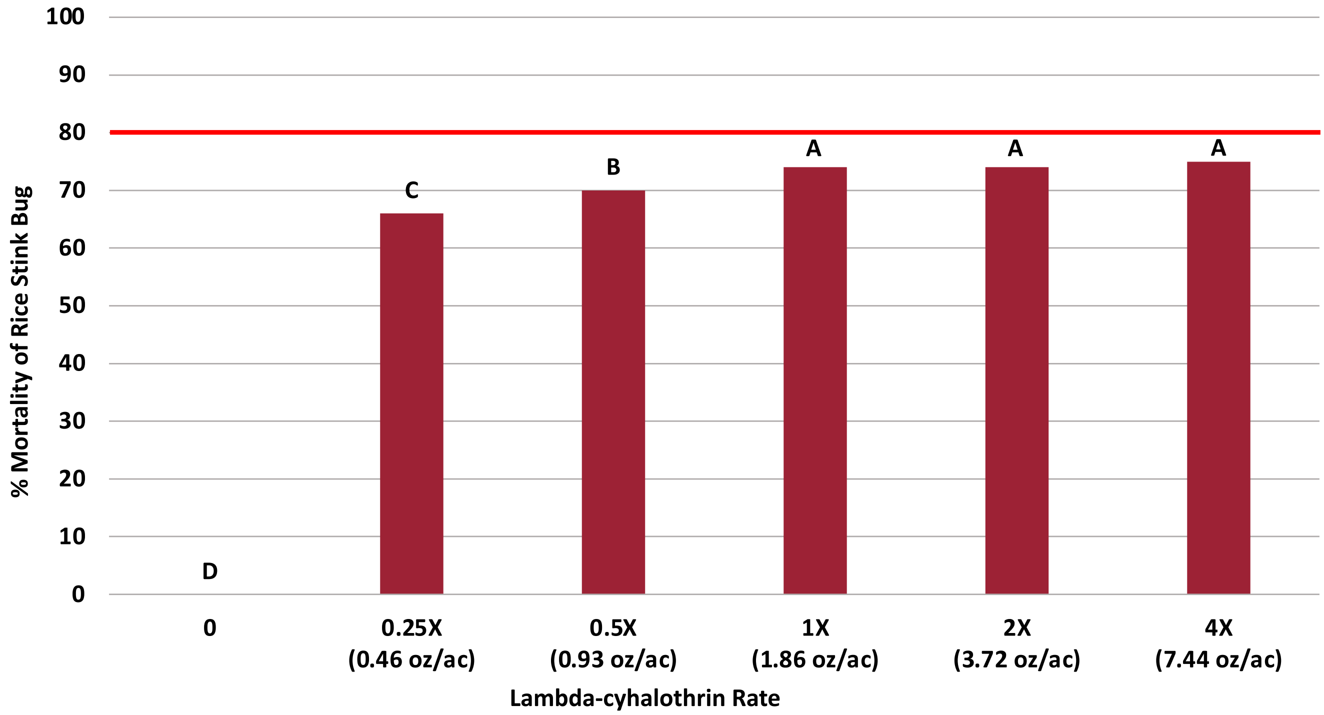

Fig. 1. Efficacy of rice stink bug exposed to multiple rates of lambda-cyhalothrin 24 h after exposure for collections made in the month of May from 2021 to 2022 throughout Arkansas. Red line shows percent mortality to be considered good control. Treatments with the same letter are not different according to Duncan's numerical range test at α = 0.05.

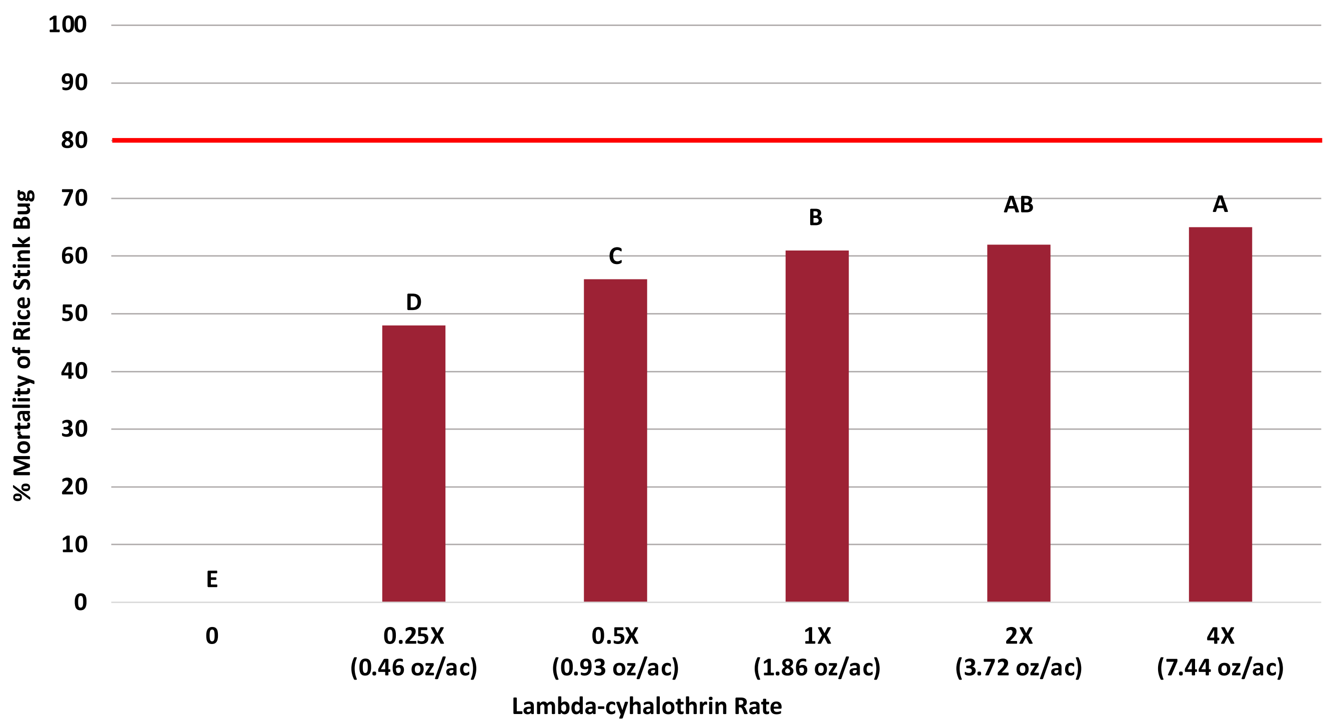

Fig. 2. Efficacy of rice stink bug exposed to multiple rates of lambda-cyhalothrin 24 h after exposure for collections made in the month of June from 2021 to 2022 throughout Arkansas. Red line shows percent mortality to be considered good control. Treatments with the same letter are not different according to Duncan's numerical range test at α = 0.05.

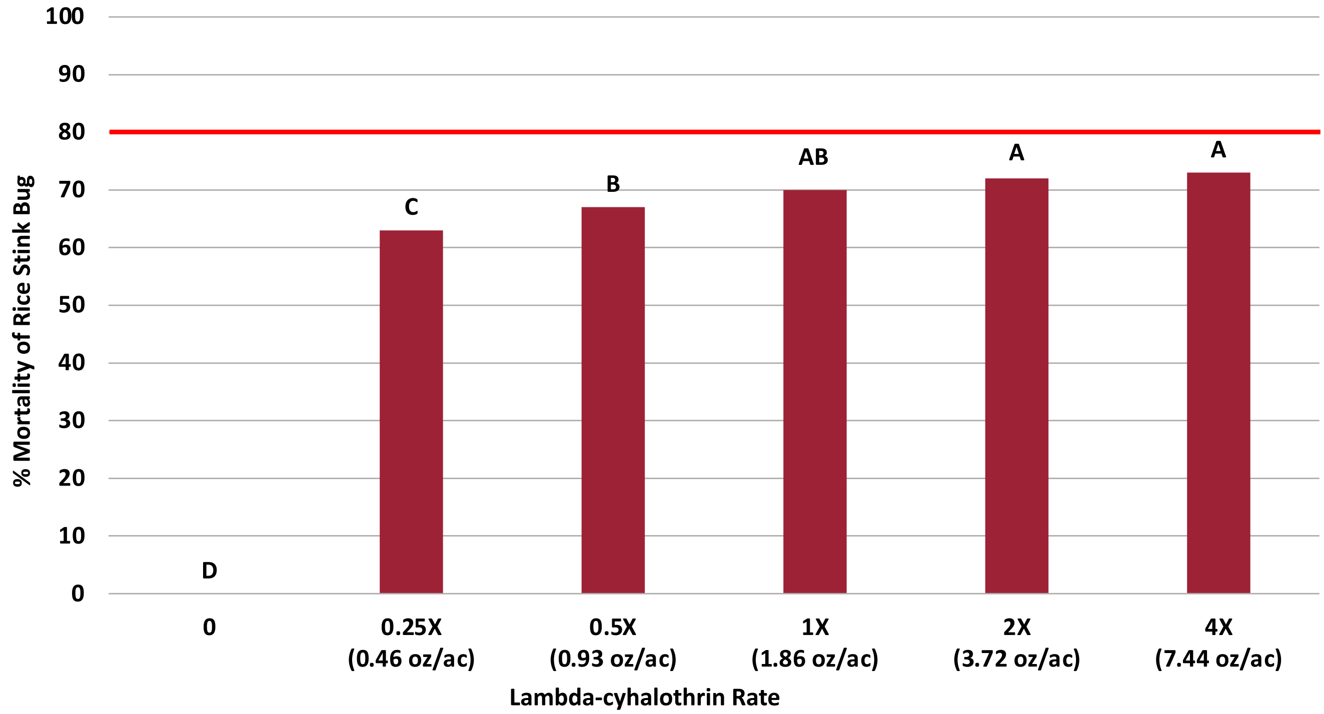

Fig. 3. Efficacy of rice stink bug exposed to multiple rates of lambda-cyhalothrin 24 h after exposure for collections made in the month of July from 2021 to 2022 throughout Arkansas. Red line shows percent mortality to be considered good control. Treatments with the same letter are not different according to Duncan's numerical range test at α = 0.05.

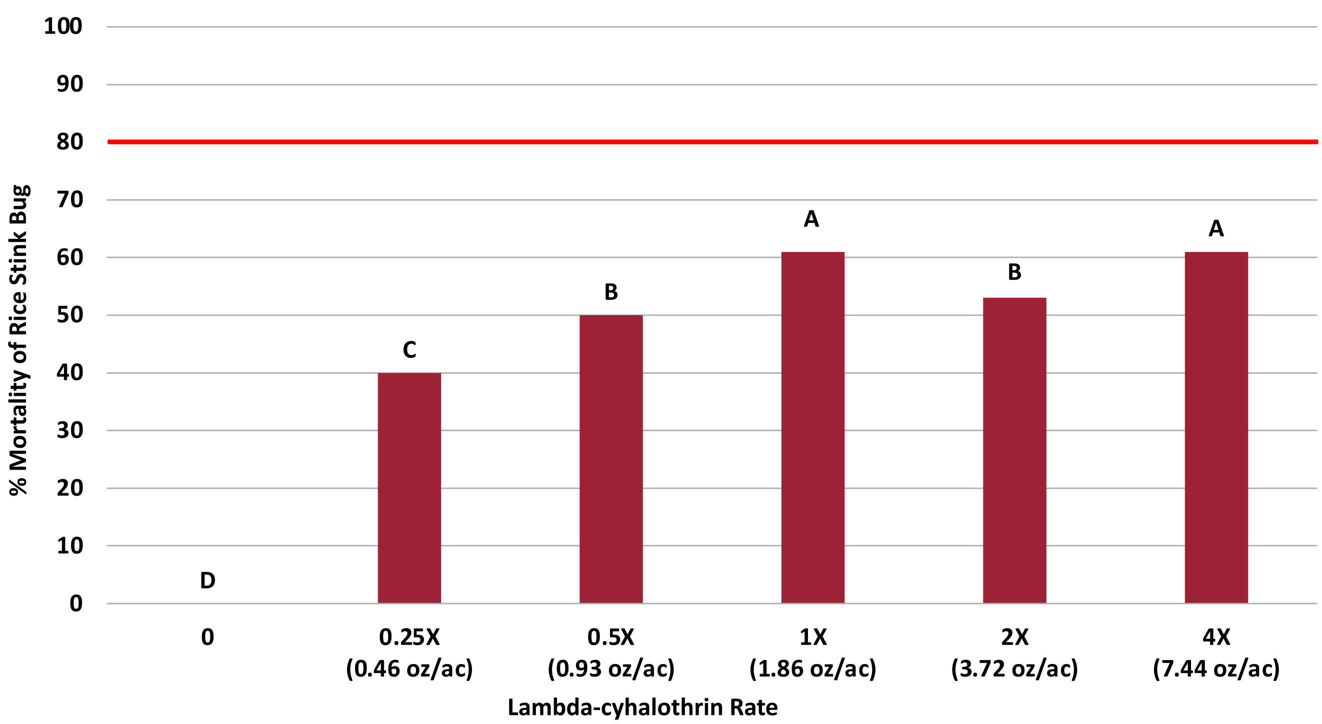

Fig. 4. Efficacy of rice stink bug exposed to multiple rates of lambda-cyhalothrin 24 h after exposure for collections made in the month of August from 2021 to 2022 throughout Arkansas. Red line shows percent mortality to be considered good control. Treatments with the same letter are not different according to Duncan's numerical range test at α = 0.05.

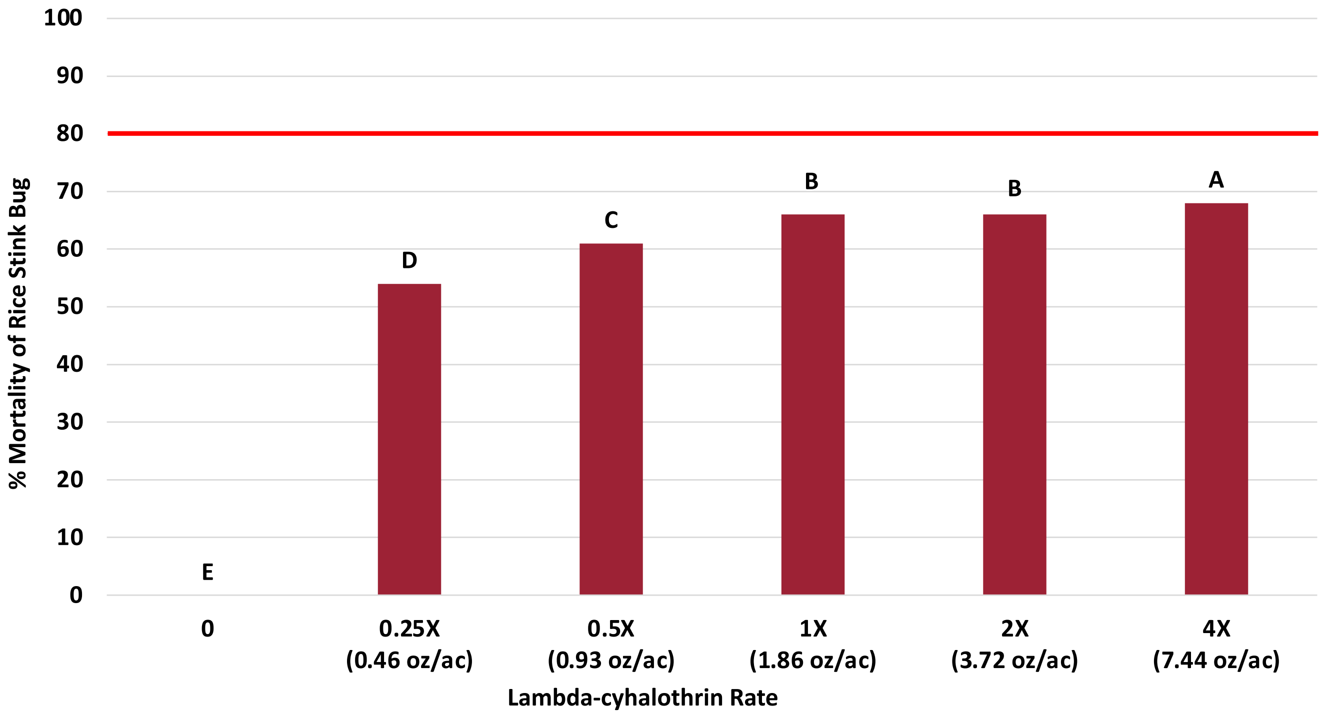

Fig. 5. Efficacy of Lambda for RSB at multiple rates 24 hours after exposure on average of 54 locations. Red line shows percent mortality to be considered good control. Treatments with the same letter are not different according to Duncan's numerical range test at α = 0.05.

Weedy Rice Control When Using Single and Sequential Applications of Oxyfluorfen

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Abstract

Weedy rice in Arkansas is resistant to HRAC/WSSA group 1 and 2 herbicides that are commonly used for control. The ROXY® Rice Production System (RRPS) provides tolerance to herbicides containing oxyfluorfen. Oxyfluorfen is a Herbicide Resistance Action Committee/Weed Science Society of America (HRAC/WSSA) group 14 herbicide labeled for preemergence (PRE) and postemergence (POST) applications in many crops. Oxyfluorfen currently is not labeled for use in rice; however, the Roxy trait in the RRPS allows for applications of the herbicide. During the 2021 and 2022 growing seasons, two independent field trials were conducted at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center near Stuttgart, Ark. The first experiment was designed to determine if there was a rate response for weedy rice control associated with oxyfluorfen applied POST at the 2-leaf growth stage of weedy rice. The second experiment was designed to determine the optimal rate of oxyfluorfen to use PRE and POST in a sequential program when the maximum annual rate could not exceed 1.5 lb ai/ac. For the rate response experiment, oxyfluorfen (ALB2024) was POST-applied at 0.5, 0.75, 1, 1.25, or 1.5 lb ai/ac when the weedy rice reached the 2-leaf growth stage. In the sequential application experiment, mixtures of clomazone and oxyfluorfen (ALB2023) (0.3 plus 0.5, 0.75, or 1 lb ai/ac, respectively) were applied PRE, followed by a POST application of oxyfluorfen that resulted in the total amount of the herbicide applied being 1.5 lb ai/ac. Weedy rice control for all treatments ranged from 57 to 73% for the rate response experiment at 35 days after treatment. In the sequential application experiment, oxyfluorfen applied PRE resulted in 46 and 70% weedy rice control at the lowest (0.5 lb ai/ac) and highest (1 lb ai/ac) oxyfluorfen rates, respectively. At 14 days after the final treatment, 78 to 81% weedy rice control was observed for all treatments when oxyfluorfen was applied sequentially. Oxyfluorfen could potentially serve to suppress weedy rice in a RRPS; however, oxyfluorfen alone will not be able to achieve complete control.

Introduction

In Arkansas, weedy rice is one of the most problematic weeds to control in a flood-irrigated rice production system (Butts et al., 2022). Smith (1988) reported that weedy rice (*Oryza sativa* L.) can reduce rice yields by 82% when present throughout the entire growing season. Weedy rice is currently resistant to WSSA group 1 and 2 herbicides, eliminating all current herbicide trait technologies in rice production in some Arkansas rice fields (Heap, 2023; Norsworthy pers. comm.).

The ROXY® Rice Production System (RRPS) is enabled by a new herbicide-resistant rice line that would allow for in-season applications of oxyfluorfen (McKenzie et al., 2021). Oxyfluorfen is a Weed Science Society of America (WSSA) group 14 protoporphyrinogen oxidase (PPO)-inhibiting herbicide that can be used 7 days prior to planting cotton (*Gossypium hirsutum* L.) and soybean [*Glycine max* (L.) Merr.], and as a post-directed spray in cotton, as well as some vegetables (Anonymous, 2014). Oxyfluorfen is labeled for the control of barnyardgrass [*Echinochloa crus-galli* (L.) Beauv.], as well as other grass and broadleaf species in windbreaks and areas of conifer and deciduous trees (Anonymous, 2014; WSSA, 2022). Limited control options for weedy rice have created a need for alternative modes of action (MOA) in Arkansas rice production.

Procedures

In 2021 and 2022, two independent field experiments were conducted at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center near Stuttgart, Ark., to determine the effectiveness of single and sequential applications of oxyfluorfen for weedy rice control. The single application experiment was designed to determine if there was a response to weedy rice control with respect to the rate of oxyfluorfen applied. The sequential application experiment was designed to evaluate weedy rice control when various rates of oxyfluorfen were applied preemergence (PRE) or postemergence (POST). Oxyfluorfen-resistant rice was planted at 22 seeds per ft of row, and all plots were 6 ft wide and 17 ft long. Soil fertility and irrigation were managed using standard Arkansas flooded rice methods (Henry et al., 2021). Each experiment was designed as a single factor, randomized complete block with four replications. In the single application experiment, clomazone was applied at 0.3 lb ai/ac PRE across all plots to control non-target grass species followed by oxyfluorfen POST at 0.5, 0.75, 1, 1.25, or 1.5 lb ai/ac. In the sequential application experiment, clomazone and oxyfluorfen (0.3 plus 0.5, 0.75, or 1 lb ai/ac) were applied PRE followed by oxyfluorfen that resulted in the total application equaling 1.5 lb ai/ac of oxyfluorfen for each of the three treatments. A nontreated

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control was included in each experiment for comparison. All treatments were applied using a CO_2-pressurized backpack sprayer calibrated to deliver 15 gal/ac with AIXR110015 nozzles at 3 mph. In the single application experiment, ratings were collected weekly following the application of oxyfluorfen. In the sequential application experiment, ratings were collected the day of and weekly after the POST application. All ratings were on a scale of 0 to 100%, with 0 representing no weed control compared to the nontreated control and 100 representing complete crop or weed destruction. Data were subjected to an analysis of variance, and means were separated using Fisher's protected least significant difference with an alpha value of 0.05.

Results and Discussion

Single Application of Oxyfluorfen

At 7 DAT, a single application of oxyfluorfen resulted in 64 to 73% weedy rice control averaged over site-year (Table 1). Oxyfluorfen applied at 0.5, 1, and 1.5 lb ai/ac resulted in 61, 68, and 72% weedy rice control 28 DAT respectively. The similarity in results at 7 and 28 DAT is not surprising considering that oxyfluorfen is a contact herbicide, meaning that maximum control will likely be reached by the 7 DAT evaluation. Based on these findings, weedy rice likely will not be controlled with oxyfluorfen alone POST, and other tactics or herbicides will be needed to further improve control. If oxyfluorfen were to become labeled in rice, then the 1.5 lb ai/ac rate of oxyfluorfen would be recommended to achieve the best weedy rice control based on these data. At 35 DAT, there was 54 to 73% weedy rice control for all treatments. Regrowth of weedy rice plants not killed with an initial application will likely occur as seen with other weeds (Anonymous, 2014).

Sequential Applications of Oxyfluorfen

An application of oxyfluorfen applied PRE resulted in 46 to 70% weedy rice control prior to the POST application (Table 2). In 2021 and 2022, the POST was applied 21 and 28 days after planting, respectively. Weedy rice control ranged from 73 to 88% at 7 days after the POST (DAPOST) application in both site-years for all rates and application timings. All rates and application timings of oxyfluorfen resulted in weedy rice control of 78 to 81% at 14 DAPOST. Based on these data, sequential applications of oxyfluorfen will not provide effective season-long weedy rice control.

Practical Applications

Findings from these experiments led to the conclusion that complete control of weedy rice with oxyfluorfen is not likely; however, oxyfluorfen could provide an alternative MOA to help suppress weedy rice. Currently, there are no weedy rice populations resistant to HRAC/WSSA group 14 herbicides. Therefore, oxyfluorfen could potentially work in all rice-producing areas of the US. However, if a label is approved, the risk of the Roxy rice trait outcrossing with weedy rice would be high considering the number of weedy rice survivors following sequential oxyfluorfen applications.

Research has shown that there is a severe penalty for weedy rice control with oxyfluorfen when applications are made later than the 2-leaf growth stage. Timely applications of oxyfluorfen, with optimal spray coverage are essential for controlling weedy rice with oxyfluorfen.

Acknowledgments

The authors would like to thank the University of Arkansas System Division of Agriculture, the Rice Research and Extension Center near Stuttgart, the Arkansas Rice Research and Promotion Board, and Albaugh Company for support of this weed control research in rice.

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Table 1. Weedy rice control 7, 14, 21, 28, and 35 days after treatment (DAT) with oxyfluorfen applied in a single postemergence application averaged over the 2021 and 2022 site-years near Stuttgart, Ark.

	Weedy Rice Control				
Rate	**7 DAT**	**14 DAT**	**21 DAT**	**28 DAT**	**35 DAT**
(lb ai/ac)	----------------------------------- % ---				
0.5	67	66	64	61 B	54 C
0.75	64	67	64	62 B	57 BC
1	68	69	66	68 AB	63 ABC
1.25	70	70	74	74 A	68 AB
1.5	73	75	76	72 A	73 A

† Means within a column followed by the same letter are not different according to Fisher's protected least significant difference (α = 0.05).

Table 2. Weedy rice control the day of, 7, 14, and 21 days after postemergence applied oxyfluorfen in sequential preemergence followed by postemergence applications, averaged over the 2021 and 2022 site-years near Stuttgart, Ark.

	Weedy Rice Control				
Rate	**Day of POST**	**7 DAPOST**	**14 DAPOST**	**21 DAPOST**	**28 DAPOST**
(lb ai/ac)	**--(%)---**				
0.5 fb 1.0	46 B	81	81	78	75
0.75 fb 0.75	59 A	80	79	72	73
1.0 fb 0.5	70 A	80	78	73	75

† Means within a column followed by the same letter are not different according to Fisher's protected least significant difference (α = 0.05).

‡ Abbreviations: POST = postemergence; DAPOST = days after postemergence; fb = followed by.

Rice Tolerance and Weed Control with Acetochlor and a Fenclorim Seed Treatment on a Sharkey Clay

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Abstract

Utilizing chloroacetamide herbicides in current rice herbicide programs would offer a new site of action for producers to control problematic weeds. Recent research has shown that a fenclorim seed treatment can facilitate delayed-preemergence applications of acetochlor by mitigating herbicide injury. However, previous research is limited to silt loam soils and has yet to evaluate the performance on a heavy clay soil. Experiments were conducted at the University of Arkansas System Division of Agriculture's Northeast Research and Extension Center, near Keiser, Ark. to determine the safening potential of a fenclorim seed treatment for microencapsulated acetochlor applications on a Sharkey silty clay. The factors evaluated various acetochlor rates at 0, 1.12, 1.68, and 2.24 lb ai/ac and a fenclorim seed treatment at 0 and 2.5 lb ai/1000-lb of seed. Additionally, barnyardgrass and Palmer amaranth control were evaluated before removing all weeds prior to flood establishment. Increasing rates, unsurprisingly, increased barnyardgrass control and rice injury. Acetochlor rates of 1.68 and 2.24 lb ai/ac, averaged over fenclorim, provided similar levels of weed control with 82% to 87% barnyardgrass control and 89% to 94% Palmer amaranth control. However, 2.24 lb ai/ac caused 34% injury compared to 1.68 lb ai/ac causing 19% injury, averaged over the fenclorim seed treatment. The fenclorim seed treatment did not influence weed control; however, the safener did improve rice tolerance to acetochlor in both forms of injury and yield. Averaged over acetochlor herbicide rate, rice injury and yield were improved by 32 and 12 percentage points, respectively. Results from this study demonstrate the ability of fenclorim to enhance rice tolerance to microencapsulated acetochlor in a conventionally flooded rice system. Additionally, fenclorim would allow for delayed-preemergence applications of acetochlor providing an alternative site of action for rice producers.

Introduction

Arkansas is the leading rice producer within the United States, and one of the most limiting factors for weed control in rice is the development of herbicide resistance and the need for new effective sites of action (Butts et al. 2022; Norsworthy et al. 2013). Problematic weeds such as barnyardgrass [*Echinochloa crus-galli* (L.) P. Beauv.] and Palmer amaranth (*Amaranthus palmeri* S. Watson) can compete with cultivated rice for sunlight, water, and nutrients reducing rice yields (Smith 1988; Spitters and Van Den Bergh 1982).

Acetochlor has been well documented for residual control of barnyardgrass providing an alternative site of action in rice (Avent et al. 2023; Fogleman 2018; Godwin 2017; Norsworthy et al. 2019). However, undesirable injury has been observed without the utilization of a herbicide safener. Recent research has demonstrated the effects of a fenclorim seed treatment to mitigate rice injury to acetochlor, but most research with acetochlor in rice has been conducted on silt-loam soils. Therefore, research was conducted in Keiser, Ark. to determine the effectiveness of a fenclorim seed treatment with various rates of acetochlor in conventionally flooded rice.

Procedures

The experiment was designed as a two-factor factorial within a randomized complete block with four replications conducted over two consecutive years. The factors included (1) microencapsulated acetochlor at 0, 1.12, 1.68, and 2.24 lb ai/ac (Warrant at 0, 3, 4.5, and 6 pt/ac) and (2) a fenclorim seed treatment at 0 and 2.5 lb ai/1000-lb of seed. Trials were initiated at the University of Arkansas System Division of Agriculture's Northeast Research and Extension Center near Keiser, Ark. on 22 April 2021 and 10 May 2022, on a Sharkey silty clay (2% organic matter, 27% sand, 24% silt, and 49% clay). 'Diamond' rice was planted at 22 seeds/ft of row, and applications of acetochlor occurred delayed-preemergence (after rice seeds had imbibed water) with AIXR 110015 nozzles at 15 GPA. Individual plots were 8 ft wide and 20 ft in length.

Rice injury and weed control were visibly evaluated 28 days after emergence (DAE) on a 0 to 100% scale with 0% representing no injury or weed control and 100% representing complete crop death or no weeds present. Palmer amaranth and barnyardgrass were among the weeds evaluated. Prior to flooding, all weeds were removed to allow for yield estimates which were collected by harvesting the entire plot on 23 September 2021 and 4 October 2022. Rough rice yield was adjusted to 12% moisture, and all plots were made relative to the nontreated no acetochlor and no fenclorim. All data were analyzed using SAS version 9.4 with the GLIMMIX procedure and appropriate data distributions. Data were pooled over years with year and replication considered random effects. Fixed effects were considered significant from analysis of variance with a P-value < 0.05, and means were separated using Tukey's honestly significant difference at $\alpha = 0.05$.

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Results and Discussion

For barnyardgrass control, 1.12 lb ai/ac provided less control than 1.68 and 2.24 lb ai/ac with 71%, 82% and 87% control, respectively (Table 1). Acetochlor rates did not influence Palmer amaranth control, with 82% to 94% control across all treatments. Additionally, the fenclorim seed treatment did not influence weed control for either species ($P \geq 0.24$). The fenclorim seed treatment not influencing barnyardgrass control and increasing rates of acetochlor improving barnyardgrass control has previously been reported by Avent et al. (2023).

The fenclorim seed treatment improved rice tolerance in the form of visible injury and rough rice yield (Table 1). Averaged over acetochlor rate, visible rice injury was reduced from 40% to 8% 28 DAE with the addition of the fenclorim seed treatment and rough rice yield was improved by 12 percentage points. Based on the nontreated yields for each year, a 12 percentage point difference in rough rice yield would be equivalent to a 28 and 26 bu./ac increase from the fenclorim seed treatment for 2021 and 2022, respectively. Additionally, by 28 DAE and averaged over fenclorim, acetochlor at 1.68 lb ai/ac caused similar levels of injury to acetochlor at 1.12 lb ai/ac with 19% and 11% injury, respectively. It is important to note, that the fenclorim seed treatment did not allow injury to exceed 17% with any rate of acetochlor. Furthermore, the fenclorim seed treatment did improve rice tolerance but not weed control with acetochlor coinciding with Avent et al. (2023).

Practical Applications

Based on the results of this experiment and others, fenclorim at 2.5 lb ai/1000 lb of seed would allow for delayed-preemergence, microencapsulated acetochlor applications in rice regardless of soil texture. Though currently not labeled for use in rice, introducing acetochlor to current herbicide programs would provide an alternative site of action to control problematic weed species. Furthermore, acetochlor would provide a non-treated, residual herbicide option for weedy rice. Utilizing a fenclorim seed treatment would allow for acetochlor applications as early as delayed preemergence with minimal risk for injury. Though data were not presented in this paper, acetochlor at 2.24 lb ai/ac caused 33% stand loss 14 DAE with the fenclorim seed treatment. Based on the high level of stand reduction, rates should be limited to less than 1.68 lb ai/ac (Warrant at 4.5 pt/ac) on a heavy clay soil if acetochlor becomes labeled for use in rice.

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Table 1. Barnyardgrass control, Palmer amaranth control, and rice injury evaluated 28 days after emergence and rough rice yield collected at harvest.

		28 days after emergence			
		Weed control			
Acetochlor†	Fenclorim	barnyardgrass	Palmer amaranth	Rice injury	Relative yield‡
lb ai/ac	lb ai/1000 lb	---	--- % ---	---	---
1.12		71 B§	84	11 B	111
1.68		82 A	89	19 B	110
2.24		87 A	94	34 A	106
	P-value¶	<0.01	0.08	<0.01	0.40
	0	78	88	40 A	103 B
	2.5	81	89	8 B	115 A
	P-value	0.24	0.72	<0.01	<0.01
Acetochlor × fenclorim					
1.12	0	69	85	25	105
	2.5	72	82	4	117
1.68	0	82	88	41	107
	2.5	83	89	8	114
2.24	0	85	94	58	98
	2.5	89	93	17	114
	P-value	0.90	0.89	0.92	0.52

† Acetochlor rates equivalent to Warrant at 3, 4.5, and 6 pt/ac.

‡ Rough rice yields were relative to the nontreated check (no acetochlor or fenclorim), which yielded 236 and 220 bu./ac for 2021 and 2022, respectively.

§ Means within a column for each factor level not containing the same letter differ according to Tukey's honestly significant difference (α = 0.05).

¶ *P*-values were generated using the GLIMMIX procedure in SAS version 9.4 with a beta distribution for weed control and injury and a normal distribution for yield.

Integration of Benzobicyclon (Rogue) into a Quizalofop-Resistant Rice System for Improved Weed Control and Reduced Selection for Resistance

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Abstract

Resistance to quizalofop-p-ethyl is the newest herbicide tolerance technology in rice fields. This technology provides resistance to the herbicides Provisia® and Highcard™ and adds a new mode of action for weedy rice control to the rice weed control portfolio. However, using additional chemistries is essential to ensure the prolonged viability of this technology and avoid weed resistance. Therefore, this study evaluated how benzobicyclon (Rogue®) fits into a Max-Ace® rice system where Highcard is used for weedy rice (*Oryza* spp.) and barnyardgrass [*Echinochloa crus-galli* (L.) P. Beauv.] control. The experiment was conducted in 2022 in Stuttgart, Arkansas, and organized in a two-factor randomized complete block with a split-plot setup. The whole-plot factor was with or without benzobicyclon postflood (POSTF), and the sub-plot factor was herbicide programs: 1) no herbicide, 2) quizalofop sprayed at early postemergence (EP) and preflood (PREF), 3) quizalofop sprayed at EP and POSTF, 4) quizalofop sprayed at PREF, and 5) quizalofop sprayed at POSTF, respectively. Weedy rice and barnyardgrass control was visually rated 4 weeks after POSTF treatments. Rough rice yields were obtained at the end of the season. For both weeds evaluated, the lowest control levels were obtained when quizalofop was only sprayed POSTF without benzobicyclon. Barnyardgrass and weedy rice control were above 95% whenever repeated herbicide applications of quizalofop were present, independently of benzobicyclon. The lowest yield was obtained in the treatment with a single application of quizalofop POSTF. The highest yields were obtained when treatments included benzobicyclon POSTF, or when quizalofop was sprayed twice in the season without benzobicyclon. The alliance of Max-Ace rice systems with an alternative herbicide like benzobicyclon is a potent weed control option to reduce the development of herbicide resistance throughout the years.

Introduction

Herbicide resistance has increased exponentially over the last few years. Among the crops with the highest number of herbicide-resistant weed species, rice ranks third with a total of fifty-two herbicide-resistant species (Heap, 2023). Therefore, it is essential to not only focus on discovering new chemistries but also repurpose the available molecules present in the market. Resistance to quizalofop-p-ethyl is the newest herbicide tolerance technology in rice fields. Among the quizalofop-resistant rice systems, Max-Ace® rice is resistant to Highcard™ (quizalofop-p-ethyl) herbicide, which contains a safener to protect this rice type from injury observed previously with a different technology (Boyd, 2021). Quizalofop is a HRAC/WSSA group 1 herbicide that inhibits the acetyl CoA carboxylase enzyme commonly used to control grasses in soybean [*Glycine max* (L.) Merr.] and cotton (*Gossypium hirsutum* L.) (WSSA, 2023).

The addition of quizalofop in the chemical control portfolio for rice is novel and is an effective ally in the control of weedy rice and herbicide-resistant weeds. Actions to ensure the prolonged viability of this technology and avoid herbicide resistance are necessary. One viable alternative is the combination of multiple sites of action throughout the crop season. Therefore, this study aimed to evaluate how benzobicyclon (Rogue®) fits into Max-Ace® with Highcard™ (quizalofop-p-ethyl) rice weed control programs.

Procedures

A field experiment was conducted in 2022 at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center, near Stuttgart, Arkansas. A Max-Ace quizalofop-resistant cultivar (RTv7231 MA) was drill-seeded at 16 seeds per foot, and plot dimensions were 6 ft wide by 17 ft long. The experiment was organized in a two-factor randomized complete block with a split-plot setup and four replications. The whole-plot factor was with or without benzobicyclon at postflood (POSTF), and the sub-plot factor was herbicide programs: 1) no herbicide, 2) quizalofop sprayed at early postemergence (EP) and preflood (PREF), 3) quizalofop sprayed at EP and POSTF, 4) quizalofop sprayed at PREF, and 5) quizalofop sprayed at POSTF, respectively. Quizalofop and benzobicyclon were applied using the Highcard and Rogue formulations at 0.107 and 0.28 lb ai/ac, respectively. Treatments with quizalofop included crop oil concentrate at 1% v/v, while treatments with benzobicyclon

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included methylated seed oil at 1% v/v. All applications were made at 3 MPH with a CO2-pressurized backpack sprayer using AIXR110015 nozzles calibrated to deliver 15 GPA. Weedy rice (*Oryza* spp.) and barnyardgrass [*Echinochloa crus-galli* (L.) P. Beauv.] control was visually rated 4 weeks after POSTF treatments. Rough rice yield data were obtained at the end of the season. Data were subjected to an analysis of variance in JMP Pro v.17, and means were separated using Tukey's honestly significant difference with an alpha value of 0.05.

Results and Discussion

The split-plot interaction was significant for all response variables, indicating an improvement in control with the addition of benzobicyclon. For both weeds evaluated, the lowest visual control levels were obtained when quizalofop was only sprayed POSTF without benzobicyclon (Table 1). Quizalofop applied POSTF without benzobicyclon obtained 70 and 61% barnyardgrass and weedy rice control, respectively. Similarly, benzobicyclon applied alone POSTF controlled 78% of the barnyardgrass plants. Barnyardgrass and weedy rice control were above 95% whenever repeated quizalofop applications were present, independently of benzobicyclon. However, using multiple herbicide sites of action throughout the season is highly recommended to avoid resistance development (Norsworthy et al., 2012). Similar to the results obtained here, Patterson et al., 2022, observed that weedy rice control with sequential quizalofop applications or one application of quizalofop with the addition of benzobicyclon at postflood were comparable.

Rough rice yield varied across treatments (Fig. 1). Besides the nontreated, the lowest yield was obtained in the treatment with a single application of quizalofop at POSTF with a rice yield of 108 bu./ac. The highest yields were obtained when treatments included benzobicyclon POSTF or quizalofop was sprayed twice in the season without benzobicyclon.

Practical Applications

Sequential applications of quizalofop or application of quizalofop followed by POSTF treatment with benzobicyclon obtained comparable weed control and yield results. However, using the same herbicide chemistry consecutively increases the risk of resistance and jeopardizes the longevity of its efficacy. The alliance of Max-Ace rice systems with an effective alternative herbicide like benzobicyclon is a potent weed control option to reduce the development of herbicide resistance.

Acknowledgments

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Table 1. Weedy rice and barnyardgrass visual control 4 weeks after postflood treatments influenced by herbicide programs for the Max-Ace rice technology with or without benzobicyclon.

Treatments	Benzobicyclon	Control (%)	
		weedy rice†	barnyardgrass
		--------------------% of nontreated--------------------	
None	without	-	-
	with	82 ab	78 bc
Quizalofop EP fb‡ quizalofop PREF	without	100 a	100 a
	with	99 a	100 a
Quizalofop EP fb quizalofop POSTF	without	96 a	100 a
	with	100 a	100 a
Quizalofop PREF	without	93 a	100 a
	with	99 a	99 a
Quizalofop POSTF	without	61 b	70 c
	with	93 a	88
		$P < 0.0001$	$P < 0.0001$

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

‡ Abbreviations: EP = early postemergence; PREF = preflood; POSTF = postflood; fb = followed by.

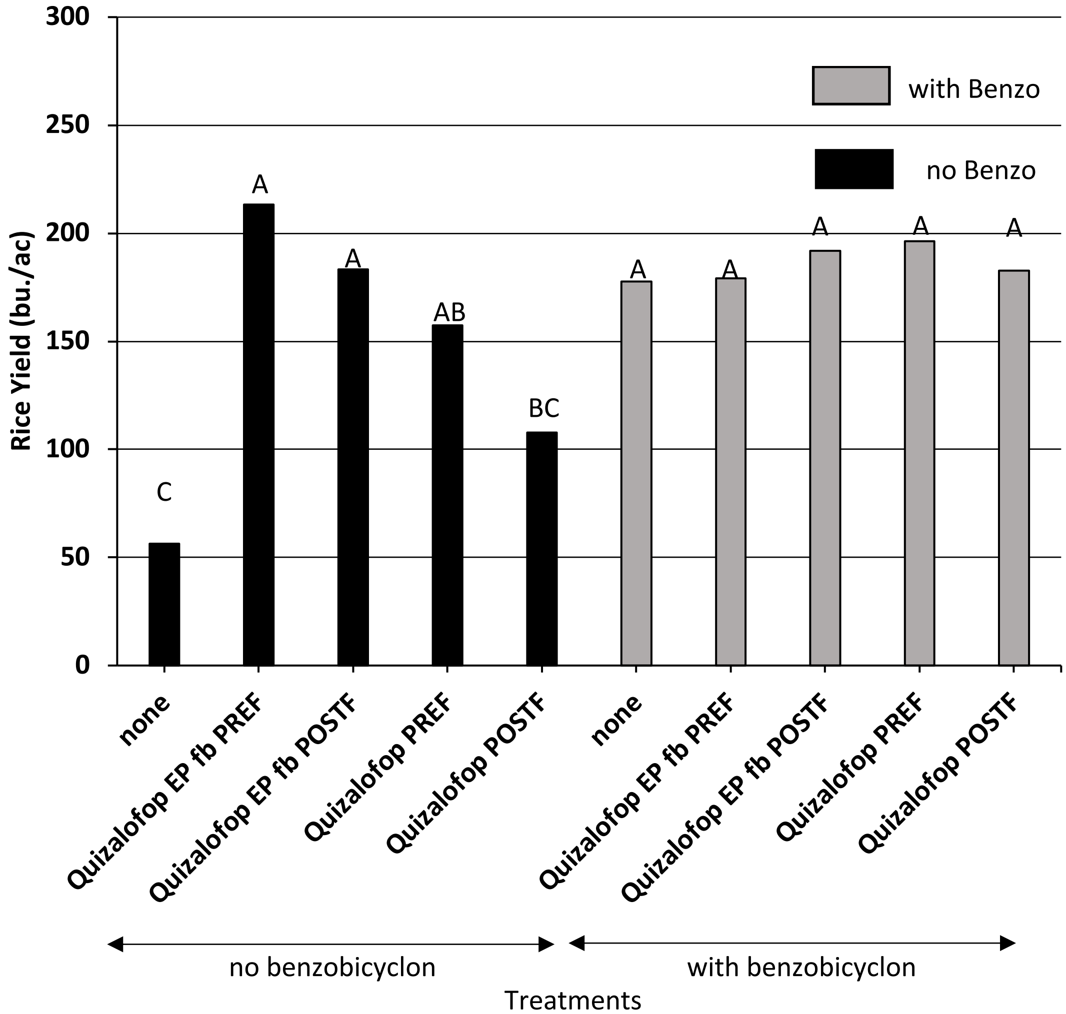

Fig. 1. Rice yield (bu./ac) following quizalofop application treatments with or without benzobicyclon (Benzo). Application timings were early postemergence (EP), preflood (PREF), or postflood (POSTF). Treatments with the same letter are not different according to Tukey's honestly significant difference test at α = 0.05.

Can Loyant-Coated Urea Mitigate Off-target Movement to Soybean?

M.C. Castner,[1] J.K. Norsworthy,[1] B. Cotter,[1] L.B. Piveta,[1] L.T. Barber,[2] and T.R. Butts[2]

Abstract

Following the commercial launch of Loyant® (florpyrauxifen-benzyl) in 2018, occurrences of off-target movement of the herbicide were prevalent onto soybean [*Glycine max* (L.) Merr.] in proximity to rice (*Oryza sativa* L.). Field experiments were conducted in 2020 and 2021, in Fayetteville, Ark., to determine if Loyant-coated urea prills could mitigate damage to soybean from the herbicide in the instance of an off-target movement event in comparison to simulated spray drift. Seven low-dose rates of Loyant ranging from 0 to 3 fl oz/ac, were applied over the top of soybean at V3 as a foliar spray or coated urea and evaluated for visible injury at 7, 14, 21, and 28 days after treatment (DAT). In addition to visible injury, soybean yield was collected at harvest. A Weibull Growth curve ($R^2 = 0.99$) was used to model visible injury at 21 DAT, and a Logistic 3P curve was fit for relative grain yield following harvest ($R^2 = 0.85$), both as a function of herbicide rate. Additionally, a Logistic 3P model was used to regress the relationship between visible injury and relative soybean yield ($R^2 = 0.86$). The predicted ($\alpha = 0.05$) Loyant dose needed to elicit 80% visible injury to soybean from a coated or foliar application was 9.8 and 0.3 fl oz/ac, respectively, which was a 33-fold increase in soybean sensitivity when foliar spray drift occurs. At the maximum tested rate of Loyant (3 fl oz/ac), 100% of soybean yield was protected when the herbicide was coated on urea (54 bu./ac) in contrast to simulated spray drift (2 bu./ac). In areas where soybean is adjacent to rice, applications of Loyant-coated urea will likely mitigate injury to soybean as opposed to spray drift of the herbicide.

Introduction

Following the commercial launch of Loyant® (florpyrauxifen-benzyl) in 2018, instances of off-target movement of the herbicide were prevalent onto soybean [*Glycine max* (L.) Merr.] adjacent to rice (*Oryza sativa* L.) fields (Walker 2018). Loyant is classified as a synthetic auxin herbicide (HRAC/WSSA group 4) that is widely used in furrow-irrigated and paddy rice to control Palmer amaranth [*Amaranthus palmeri* (S.) Wats.] and rice flatsedge (*Cyperus iria* L.) with some selectivity towards sensitive barnyardgrass [*Echinochloa crus-galli* (L.) P. Beauv.] populations. Additionally, Loyant is also an effective chemical option for levee weed management (Barber et al., 2022).

Unlike dicamba, volatility of Loyant is not a major concern (B. Cotter, unpublished data) due to inherent chemical properties of the latter herbicide. Although volatility is not a concern with Loyant, physical spray drift of the herbicide onto soybean is still a vital concern (Butts et al., 2022). By coating herbicide onto fertilizer prills, off-target movement may be mitigated to adjacent soybean due to a greater mass that can better resist cross-wind movement. In addition to reducing drift, coating fertilizer prills may reduce contact with foliage and confine soil coverage to a small area surrounding the prill if off-target movement were to occur. Herbicidal activity of Loyant is greater as a foliar spray than when applied to the soil, which may limit damage to soybean if Loyant-coated fertilizer prills land in the vicinity of plants.

Procedures

To evaluate the effectiveness of Loyant-coated urea prills in reducing damage to soybean from a simulated off-target movement event compared to foliar drift of the herbicide, a field experiment was conducted at the Milo J. Shult Agricultural Research and Extension Center, in Fayetteville, Arkansas, in 2020 and 2021. A single glyphosate- and glufosinate-resistant soybean variety was planted onto conventionally prepared beds on a 36 in spacing at 145,000 seeds/ac with each plot measuring 12 ft by 20 ft (four rows), with the outside two rows serving as a buffer between plots. The experiment was arranged as a two-factor factorial (application method by herbicide rate) randomized complete block design with four replications. For simulated foliar drift, Loyant was applied at 0.1, 0.2, 0.4, 0.8, 1.5, and 3 fl oz/ac with a 1X being 16 fl oz/ac. A CO_2-pressurized sprayer calibrated to 15 GPA was used to treat the two center rows with AIXR110015 nozzles. For simulated drift of Loyant-coated urea, 2.84 fl oz of the concentrated herbicide was mixed with 50 lb of urea (equivalent to Loyant at 16 fl oz/ac coated onto 282 lb/ac urea) in a concrete mixer for even distribution. Plot area was used to calculate the specific weight of Loyant-coated urea needed to achieve the equivalent foliar rates, meaning that lower drift rates likewise have less herbicide-coated urea prills and coverage, which would be representative of a real-world aerial fertilizer application. All Loyant-coated urea treatments were applied by hand to the center two rows of each plot totaling 120 ft^2. All treatments were applied when soybean reached V3 and foliar spray treatments contained methylated seed oil at 8 fl oz/ac. The experiment was maintained weed-free from planting until harvest.

Soybean was evaluated for visible injury at 7, 14, 21, and 28 days after treatment (DAT) on a scale of 0 to 100%, indicating no injury present and crop death, respectively. In addition to visible

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injury, soybean yield was collected at harvest. A Weibull Growth curve was used to model visible injury at 21 DAT (when synthetic auxin injury is typically most pronounced), and a Logistic 3P curve for yield following harvest. In addition to the other two regression analyses, a Logistic 3P model was used to address the relationship of visible injury and relative soybean yield. All data were averaged over the 2020 and 2021 site-years.

Results and Discussion

At 21 DAT, damage to soybean from simulated foliar spray drift was magnitudes greater than herbicide-coated applications at each of the seven evaluated drift rates of Loyant, with visible injury from the highest rate of the latter averaging <25% (R^2 = 0.99) (Fig. 1). The predicted (α = 0.05) florpyrauxifen-benzyl dose needed to elicit 80% visible injury to soybean from a coated or foliar application was 9.8 and 0.3 fl oz/ac, respectively, which was a 33-fold increase in soybean sensitivity when simulated foliar spray drift occurred. It is not surprising that coated applications elicited less of a response to soybean because of reduced foliar coverage and plant uptake from the soil profile.

At the maximum evaluated rate of Loyant (3 fl oz/ac), 100% of soybean yield was protected when the herbicide was coated on urea (54 bu./ac) in contrast to simulated spray drift where plots averaged 2 bu./ac (R^2 = 0.85) (Fig. 2). The relationship between visible soybean injury and relative yield indicates that soybean can withstand damage up to approximately 60% before grain yield begins to decline (R^2 = 0.86) (Fig. 3). Once visible injury reached 60%, relative yield declined in a linear fashion by 2.6 percentage points per 1 percentage point increase in injury, suggesting that soybean can no longer compensate for herbicide damage. Behrens and Leuschen (1979) documented similar results from a single dicamba exposure on vegetative soybean, where visible injury between 60% to 70% began to decrease yield. With respect to dicamba on sensitive soybean, rates typically need to be similar to a tank-contamination event or exposed during reproductive development for yield loss to occur (Solomon and Bradley, 2014). Based on these data, coating urea with Loyant is a viable option to mitigate herbicide drift from applications made to rice where soybean is often in proximity.

Practical Applications

Injury to soybean from applications of Loyant has the potential to impact soybean producers in areas where rice and soybean rotations are common. Based on data collected from these field experiments, Loyant-coated urea may be a viable option to mitigate drift potential while also reducing costs by merging fertilizer and herbicide applications instead of applying them individually.

Acknowledgments

We would like to thank the University of Arkansas System Division of Agriculture, Jonathan McCoy and the Stuttgart Rice Research and Extension Center, as well as the Arkansas Rice Research and Promotion Board for support in conducting this research.

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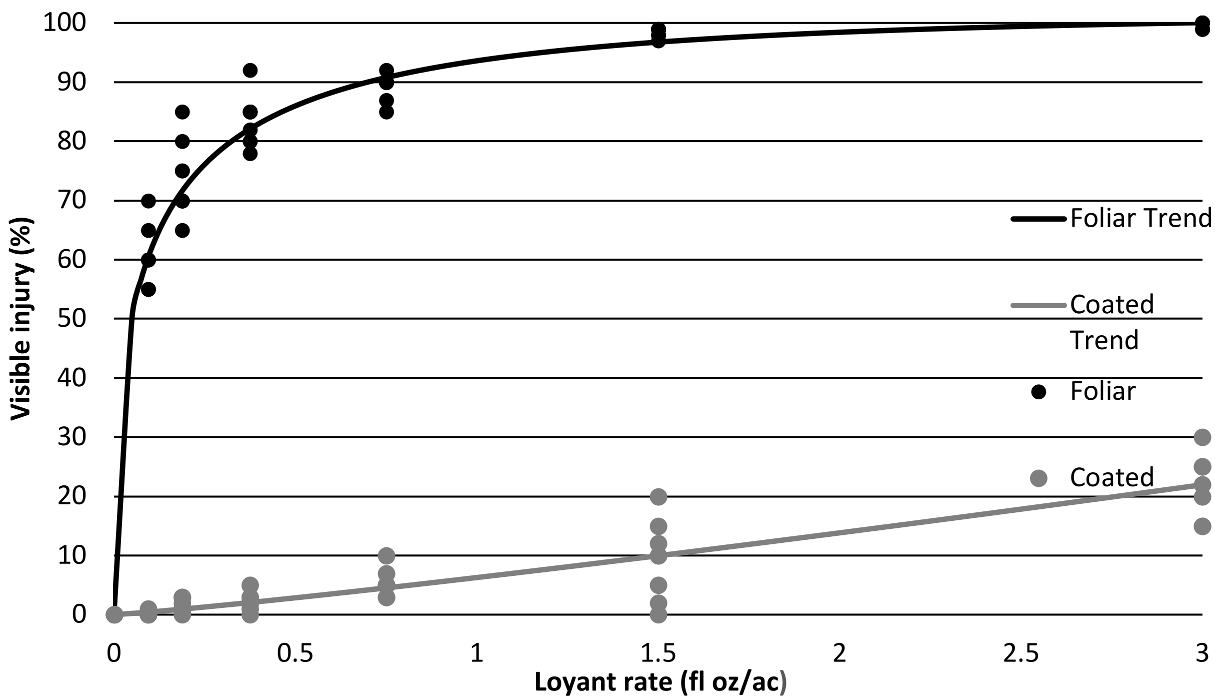

Fig. 1. Regression analysis using a Weibull Growth Model (Y=a(1-Exp(-(rate/b)c))) to predict soybean injury from low rates of Loyant 21 days after treatment in 2020 and 2021. Lines separated by application method. A = asymptote, b = inflection point, and c = growth rate.

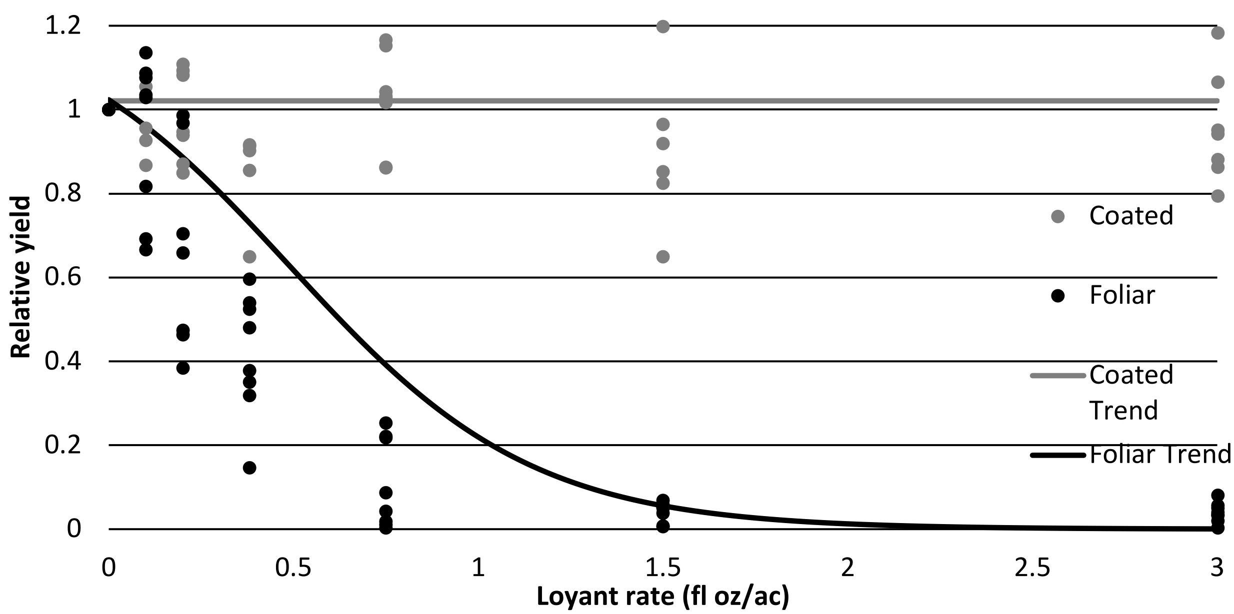

Fig. 2. Regression analysis using a Logistic 3P Model (Y=c/(1+Exp(-a*(rate-b)))) to predict relative soybean yield from low rates of Loyant using harvest data collected in 2020 and 2021. Lines separated by application method. CA = growth rate, b = inflection point, and c = asymptote.

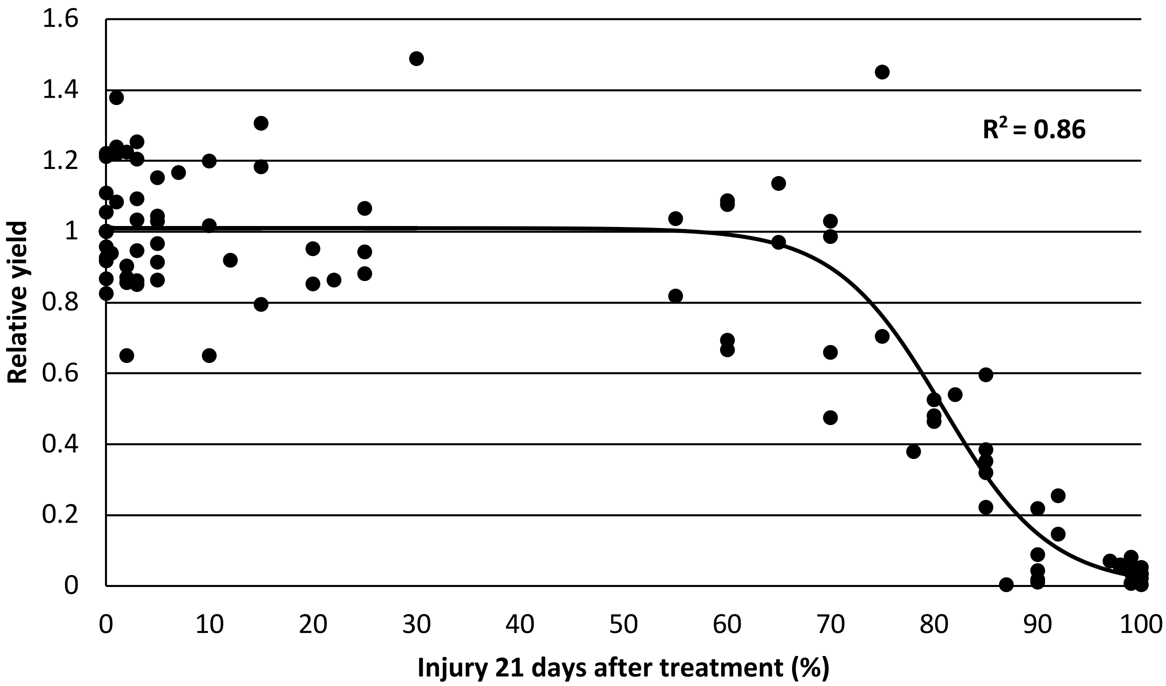

Fig. 3. Regression analysis using a Logistic 3P Model (Y=c/(1+Exp(-a*(injury-b)))) to predict relative soybean yield collected at harvest as a function of percent visible injury observed at 21 days after treatment in 2020 and 2021. The model represents visible injury caused by foliar and coated application methods averaged for both site-years. A = growth rate, b = inflection point, and c = asymptote.

Effect of Simulated Drift Rates of Reviton (Tiafenacil) on Rice

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Abstract

Reviton (tiafenacil) is a new protoporphyrinogen oxidase (PPO)-inhibiting herbicide labeled for burndown applications. However, as burndown applications can be stretched across a wide range of dates in the Mid-South, there can be a high potential for off-target movement to occur onto emerged crops. As a result, research was needed to determine the effects of simulated drift rates of Reviton to rice (*Oryza sativa* L.). In 2022, an experiment was established in Lonoke, Arkansas, St. Joseph, Louisiana, and Stoneville, Mississippi, to assess the tolerance of rice to simulated drift rates of Reviton herbicide at two exposure timings. Reviton simulated drift rates of 1/8, 1/16, 1/32, 1/64, 1/128, and 1/256 of the labeled rate (1 fl oz/ac) were applied to determine the potential consequences of off-target movement on rice. No height or rough rice yield differences resulted from exposure to simulated drift rates of Reviton. Reviton caused greater visual injury to rice at higher simulated drift rates (particularly 1/8 and 1/16 of the labeled rate) when exposure occurred at an early growth stage; however, rice recovered without yield reduction. This research indicates rice growers should not have major concerns about Reviton drift onto their rice crop; however, appropriate measures should always be taken to reduce off-target movement of herbicide applications.

Introduction

Growers in the mid-South are in constant need of new and improved methods to control early season herbicide-resistant weeds. Reviton (tiafenacil) is a new protoporphyrinogen oxidase (PPO)-inhibiting herbicide labeled for burndown applications to assist in starting clean ahead of planting the crop. Starting clean is an important first step of establishing effective, season-long weed control (Norsworthy et al., 2012). However, as burndown applications can be stretched out across a wide range of dates in the mid-South, there can be a high potential for off-target movement to occur onto emerged crops. Previous research has illustrated the severe impacts of spray drift occurring from both ground and aerial applications onto susceptible plant species (Butts et al., 2022). Even further research has shown the severe negative impacts that herbicide drift specifically onto rice (*Oryza sativa* L.) can cause (McCoy et al., 2021a, 2021b). As a result, it is critical to understand the impacts Reviton would have on rice if it were to move off-target. The objective of this research was to assess the effects of simulated drift rates of Reviton at multiple exposure timings on rice.

Procedures

In 2022, an experiment was established in Lonoke, Ark., St. Joseph, La., and Stoneville, Miss., to assess the tolerance of rice to simulated drift rates of Reviton herbicide at two exposure timings. Treatments were arranged in a randomized complete block design with four replications. Simulated drift rates of Reviton were applied at 0.13, 0.063, 0.032, 0.016, 0.008, and 0.004 fl oz/ac (1/8, 1/16, 1/32, 1/64, 1/128, and 1/256 of the labeled rate of Reviton). These applications were applied to one-leaf rice (EPOST) and three-leaf rice (MPOST) with a spray volume of 10 GPA. Data collected consisted of visual injury ratings using a scale of 0% to 100% where: 0% is no visual injury and 100% is complete plant death. Visual injury ratings were recorded at 1 and 3 weeks after application (WAA). Rice heights (average of five plants) were also recorded 3 weeks after the EPOST application and 2 weeks after the MPOST application. Rice was harvested using a plot combine, and rough rice yield was adjusted to 13% moisture. Data were subjected to analysis of variance and means were separated using Tukey's honestly significant difference test at a 5% level of significance.

Results and Discussion

Averaged across locations, rice exposed to the highest rate of Reviton (0.13 fl oz/ac) at EPOST resulted in the most visual injury (47%) 1 WAA but was reduced to only 13% injury by 3 WAA (Figs. 1 and 2). Six percent or less visual rice injury was observed 3 WAA when rice was exposed to Reviton EPOST at rates equal to or less than 0.063 oz/ac. Twenty percent or less visual injury was observed 1 WAA for all rates of Reviton at the MPOST timing and no crop response was observed 3 WAA. No height or rough rice yield differences resulted from exposure to simulated drift rates of Reviton (Figs. 3 and 4). At the rates in which rice was exposed in these studies, Reviton caused greater visual injury at higher simulated drift rates (particularly 1/8 and 1/16 of the labeled rate) when occurring at an early growth stage (1-leaf rice) but rice recovered without yield reduction.

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Practical Applications

This research indicates rice growers should not have major concerns about Reviton drift onto their rice crop. Although visual injury may be observed, particularly early season, results indicated it would not negatively impact rice growth or yield. Though these experiments suggest that a drift rate of Reviton will not cause lasting damage to rice, appropriate measures should always be taken to reduce off-target herbicide applications. This is especially true as Reviton is most frequently applied in tank-mixture with glyphosate or clethodim, both of which are much more detrimental to rice even at drift rates.

Acknowledgments

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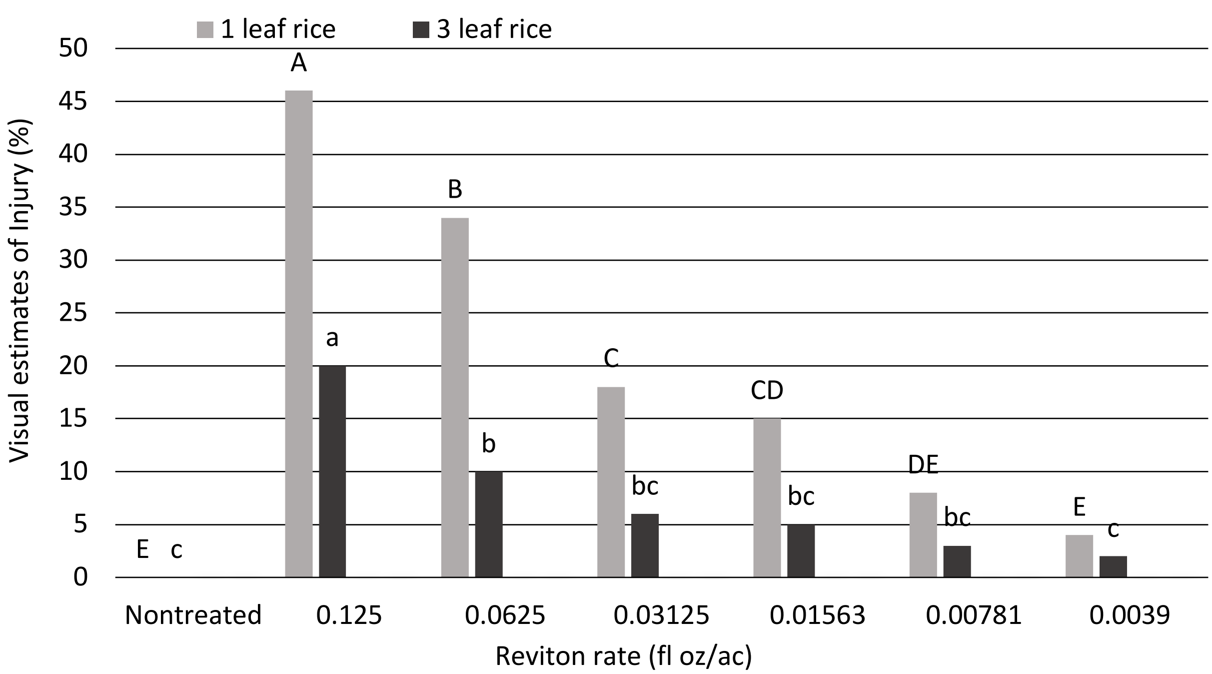

Fig. 1. Rice visual injury 1 week after 1 leaf rice and 3 leaf rice application timings of Reviton simulated drift rates of 1/8, 1/16, 1/32, 1/64, 1/128, 1/256x of the labeled rate (1 fl oz/ac). Bars with the same letter within application timing are not different according to Tukey's honestly significant difference (α = 0.05).

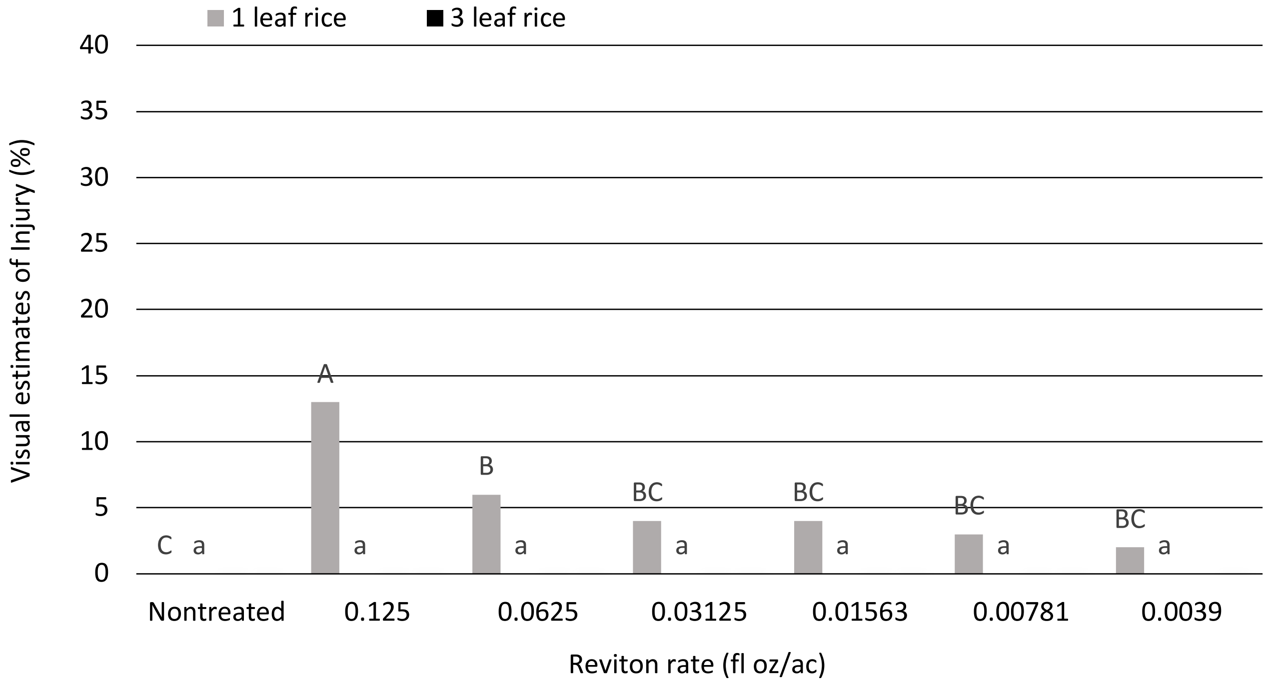

Fig. 2. Rice visual injury 3 weeks after 1 leaf rice and 3 leaf rice application timings of Reviton simulated drift rates of 1/8, 1/16, 1/32, 1/64, 1/128, 1/256x of the labeled rate (1 fl oz/ac). Bars with the same letter within application timing are not different according to Tukey's honestly significant difference (α = 0.05).

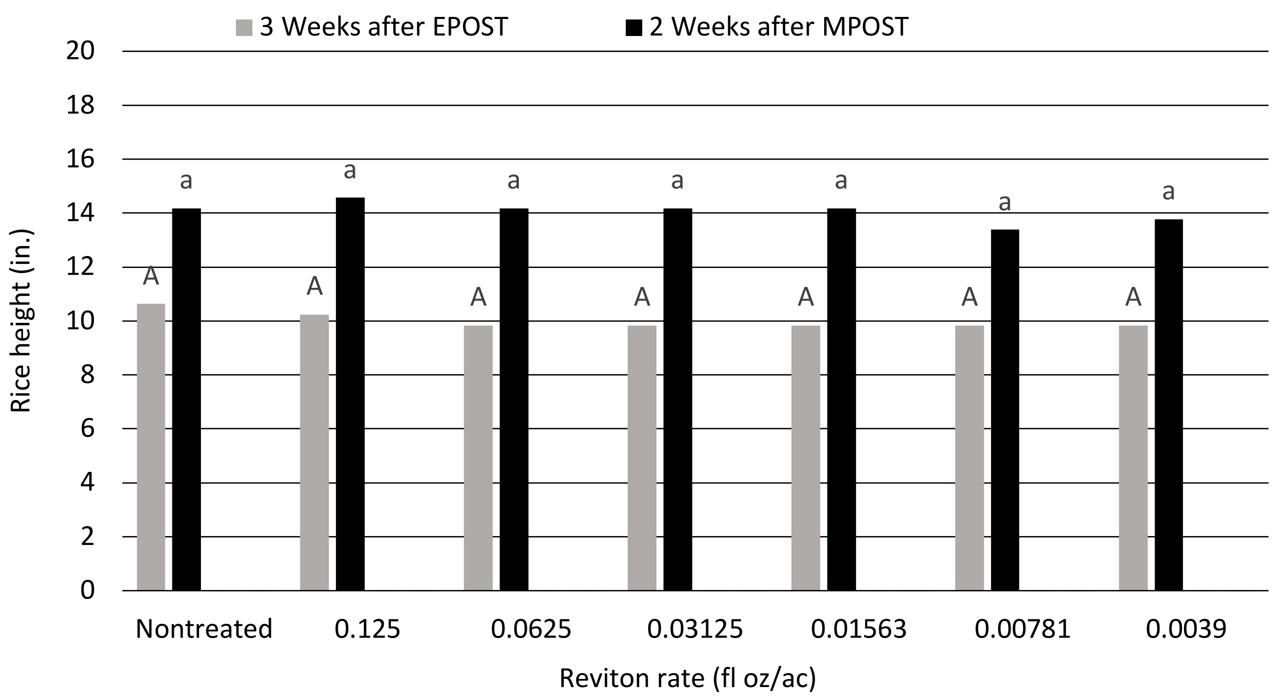

Fig. 3. Rice heights taken 3 weeks after EPOST and 2 weeks after MPOST applications of Reviton simulated drift rates of 1/8, 1/16, 1/32, 1/64, 1/128, 1/256x of the labeled rate (1 fl oz/ac). Bars with the same letter within application timing are not different according to Tukey's honestly significant difference (α = 0.05).

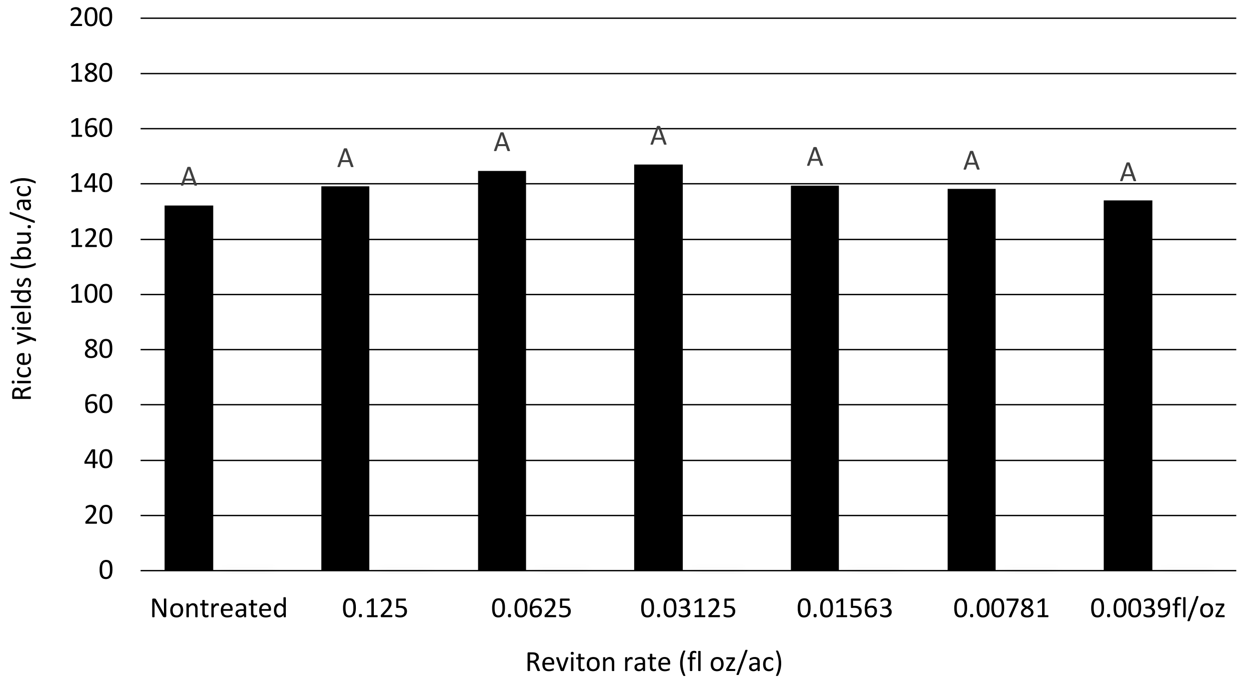

Fig. 4. Rough rice yield averaged across application timings of Reviton simulated drift rates of 1/8, 1/16, 1/32, 1/64, 1/128, 1/256x of the labeled rate (1 fl oz/ac). Bars with the same letter are not different according to Tukey's honestly significant difference (α = 0.05).

Bed Width and Drill Spacing Effect on Weed Management in Furrow-Irrigated Rice

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Abstract

Furrow-irrigated rice (*Oryza sativa* L.), or row rice, has increased in acreage in Arkansas in the past few years. This practice allows growers to potentially grow rice on steeper ground that would require a vast number of levees that is labor and time intensive. However, this non-traditional rice growing method has a weed management drawback. The removal of the flood as a means of weed control places additional pressure on other weed management strategies and potentially different herbicide programs. Therefore, the objectives of this research were to determine if the manipulation of drill row spacing and bed width would influence season-long weed control. Two studies were seeded with hybrid rice RT7521 FP in 2021 and 2022 at Lonoke and Pine Tree, Ark. to evaluate treatments that consisted of three bed widths (30-, 38-, and 60-in.) and four drill row spacings (5-, 7.5-, 10-, and 15-in.). Barnyardgrass [*Echinochloa crus galli* (L.) P. Beauv.] density was assessed at the 5- to 6-leaf rice stage and preharvest. Canopy closure was captured with aerial digital images from a small, unmanned aircraft system (sUAS) collected at the 3-6 leaf and panicle differentiation rice stages. Rough rice yield was harvested with a plot combine and adjusted to 13% moisture. In general, barnyardgrass densities were lower across narrower drill row spacings (≤7.5-in.) and bed widths (30-in.) early in the season; however, little differences were seen at the later preharvest timing. Canopy closure responded similarly as narrower drill row spacing and bed width had greater canopy closure. Rough rice yield was impacted less by drill row spacing and bed width, but narrower drill row spacing and bed width had a slightly higher numerical yield increase. Early findings suggest that a grower choosing this method of rice management should choose the narrowest drill row spacing allowed by their equipment and the narrowest bed widths that they can obtain to maximize weed management efforts.

Introduction

With an increased adoption of furrow-irrigated rice (*Oryza sativa* L.), or row rice, in Arkansas, new challenges in weed control have emerged. In 2021, approximately 240,000 ac were planted to furrow irrigated rice in Arkansas (Hardke, 2022). The growing of rice with the absence of a flood allows for weeds to emerge in moist soils in-between watering prior to crop canopy closure. Additionally, herbicide resistance has steadily increased, particularly in barnyardgrass [*Echinochloa crus galli* (L.) P. Beauv.] which is the most problematic weed in Arkansas rice (Butts et al., 2022), resulting in the need for alternative management strategies (Heap, 2023). Weed management programs need to shift to aid in control prior to canopy closure. Cultural practices such as drill row spacing and bed width may be used to aid in weed management efforts. The objective of this research was to determine if the manipulation of drill row spacing, and bed width would influence season-long weed control.

Procedures

Studies were conducted in the summer of 2021 and 2022 at the University of Arkansas at Pine Bluff Small Farm Outreach Center near Lonoke, Ark., and at the University of Arkansas System Division of Agriculture's Pine Tree Research Station near Pine Tree, Ark. Hybrid rice cultivar RT7521 FP was drill seeded. The experimental design was a randomized complete block split-plot design with 4 replications. Treatments consisted of 3 bed widths (30-, 38-, and 60-in.) and 4 drill row spacings (5-, 7.5-, 10-, and 15-in.). The herbicide program consisted of Command and Sharpen applied PRE (12.8 and 3 oz/ac, respectively), with no POST application applied to be able to fully assess the impact of the cultural treatments. Rice was monitored and managed according to university recommendations regarding fertility and pest control (Barber et al, 2020). Row rice was irrigated as needed usually around every 7 days unless a rainfall event had occurred. Barnyardgrass densities were assessed at the 5- to 6-leaf rice stage and preharvest. Canopy closure (%) was captured with aerial digital images from a small, unmanned aircraft system (sUAS) collected at the 3-6 leaf and panicle differentiation rice stages. Rough rice yield was harvested with a plot combine and adjusted to 13% moisture. Data were subjected to analysis of variance and means were separated using Tukey's honestly significant difference at a 5% level of significance.

Results and Discussion

Barnyardgrass densities at 5- to 6-leaf stage rice generally were lower with narrower drill spacing (≤7.5-in.) across bed widths.

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[4] Professor and Assistant Professor, respectively, Department of Plant and Soil Sciences, Mississippi State University, Stoneville.

Densities at this stage were also lower with narrower bed widths (30-in.), suggesting that early in the season narrow drill spacing and narrower bed widths would be the best scenario to help reduce early weed competition (Fig. 1). Also, by preharvest, data suggest that numerically the narrow drill row spacing (5-in.) on narrow bed widths (30-in.) was a better option than narrow drill spacing on wider bed widths (Fig. 2). Rice canopy closure data suggest that narrower drill spacing (≤7.5-in.) across all bed widths would allow for earlier canopy closure (Fig. 3). Later in the season, canopy closure was not affected by drill row spacing as much as the earlier timing (Fig. 4) indicating the 15-in. drill row spacing was able to completely canopy by the panicle differentiation growth stage. However, the earlier canopy closure observed in narrower drill row spacings is important with the suppression of new weed growth as the earlier canopy closure occurs, the better a crop is likely to shade out newly emerging weeds. This reduced amount of time for potential emergence could be the difference in a successful weed program and a failure. Rough rice yields were not as impacted as other parameters by drill row spacing or bed width (Figs. 5 and 6). Data shows that there were higher numerical rice yields with narrower drill row spacings (≤7.5-in.) and narrower bed widths (≤38-in.). This small difference could have contributed to earlier shading of the narrow drill spacing combined with faster water wicking across the narrow beds. Wider drill rows allow for more evaporation with more sunlight reaching the ground and wider bed widths may result in longer required time periods for water to wick across the bed for complete saturation.

Practical Applications

Initial findings in this study suggest that growers who choose to plant furrow-irrigated rice should plant with the narrowest drill spacing their equipment allows (5-in.) along with a narrower bed width (30-in.). These practices paired with a sound herbicide program with overlapping residuals and a timely irrigation schedule are key to season-long weed management success. If wider drill row spacings (15-in.) were to be adopted due to an influx in the availability of precision planting equipment, additional weed management efforts, both cultural and chemical, would be required to maintain similar levels of weed control as in narrower drill row spacings.

Acknowledgments

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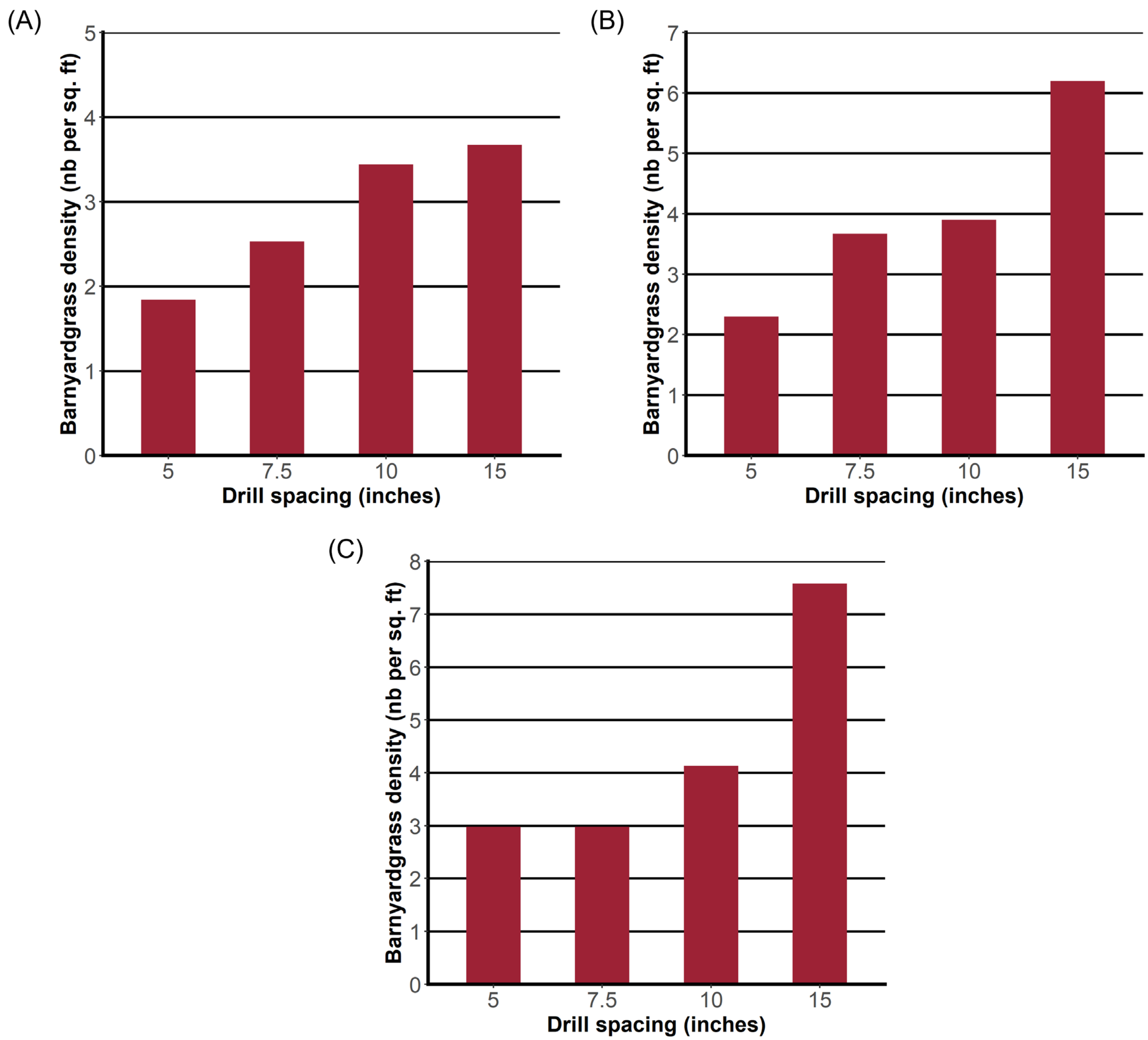

Fig. 1. Barnyardgrass density at the 5- to 6-leaf rice stage as impacted by drill row spacing within each bed width of 30-in. (A), 38-in. (B), and 60-in. (C).

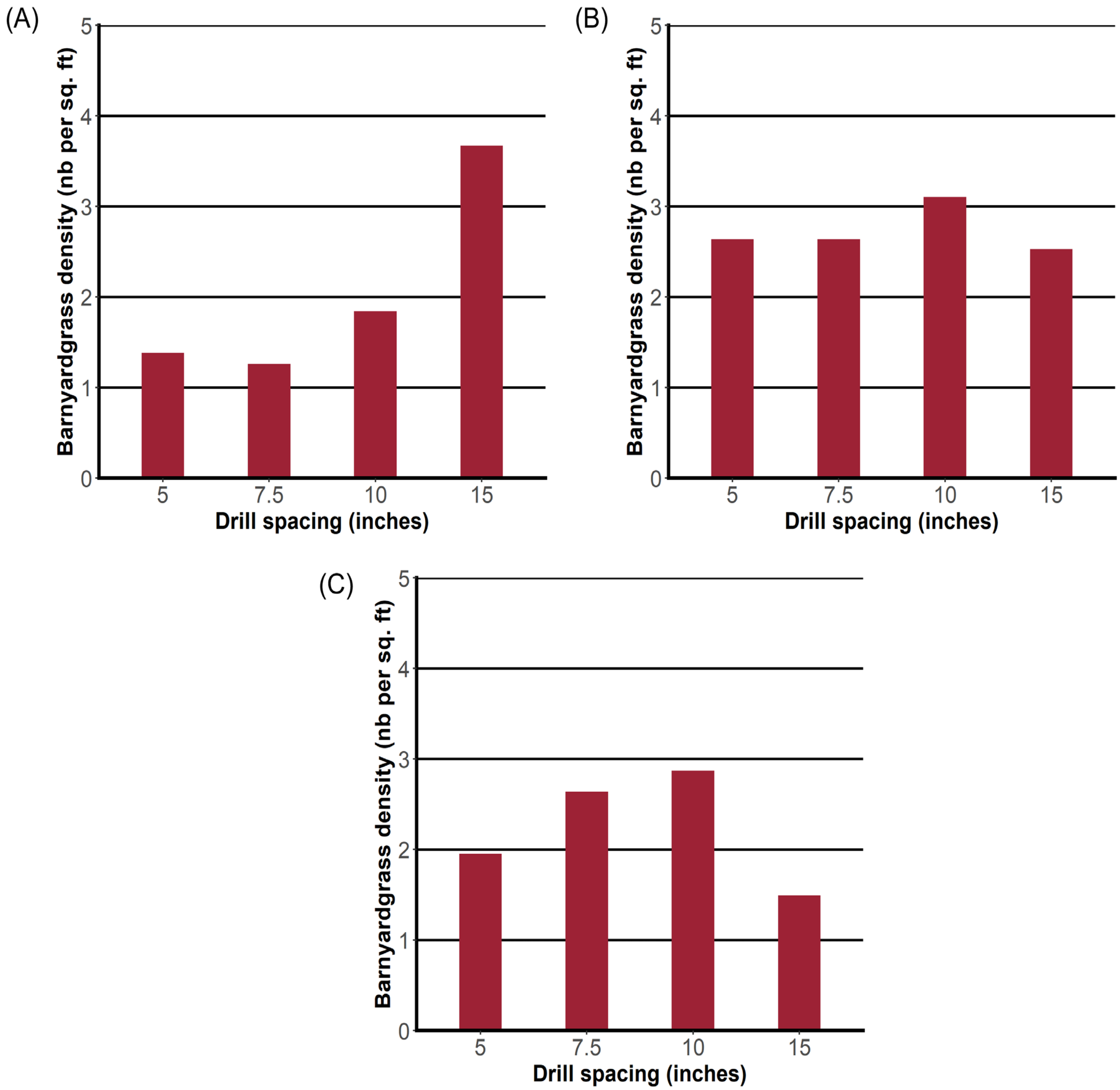

Fig. 2. Barnyardgrass density at preharvest as impacted by drill row spacing within each bed width of 30-in. (A), 38-in. (B), and 60-in. (C).

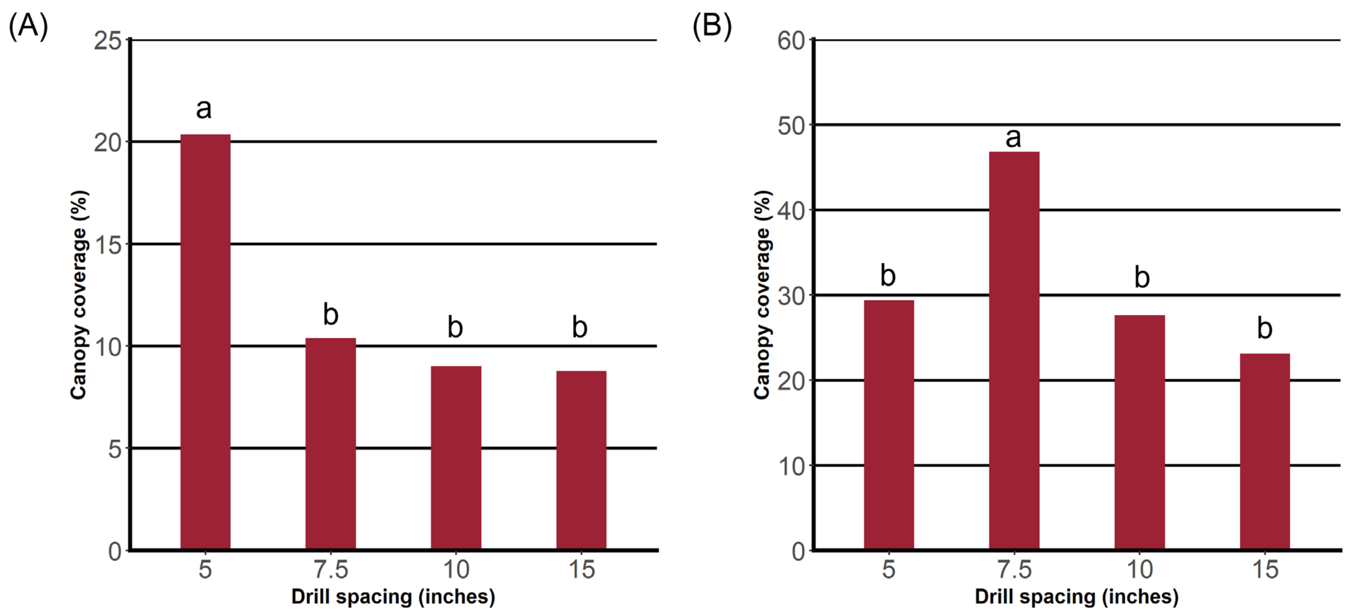

Fig. 3. Rice canopy coverage (%) in Lonoke (A) and Pine Tree (B) across bed widths at the 3-6 leaf rice stage. Bars with the same letter are not different according to Tukey's honestly significant difference (α = 0.05).

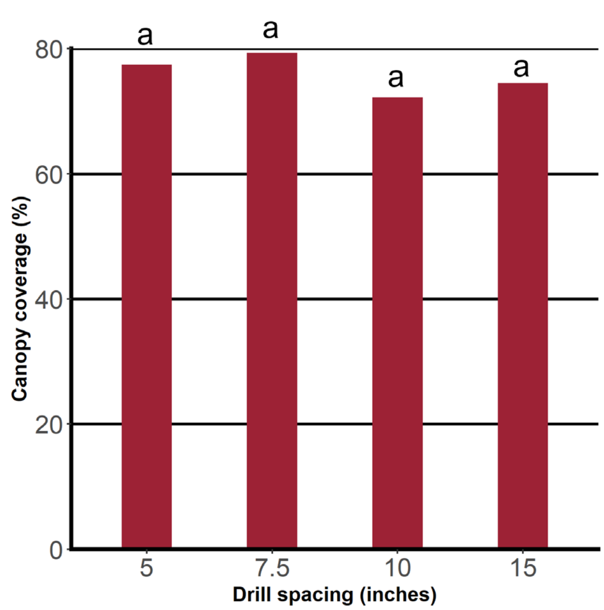

Fig. 4. Rice canopy coverage (%) across locations and bed widths at the panicle differentiation rice stage. Bars with the same letter are not different according to Tukey's honestly significant difference (α = 0.05).

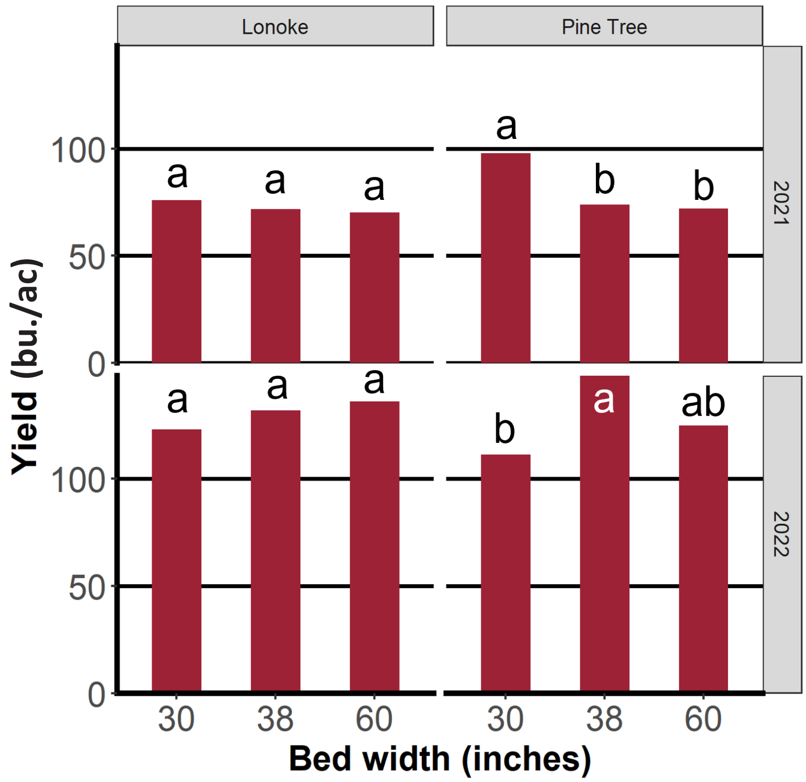

Fig. 5. Rice yield as affected by bed widths by year and location. Bars within each panel with the same letter are not different according to Tukey's honestly significant difference (α = 0.05).

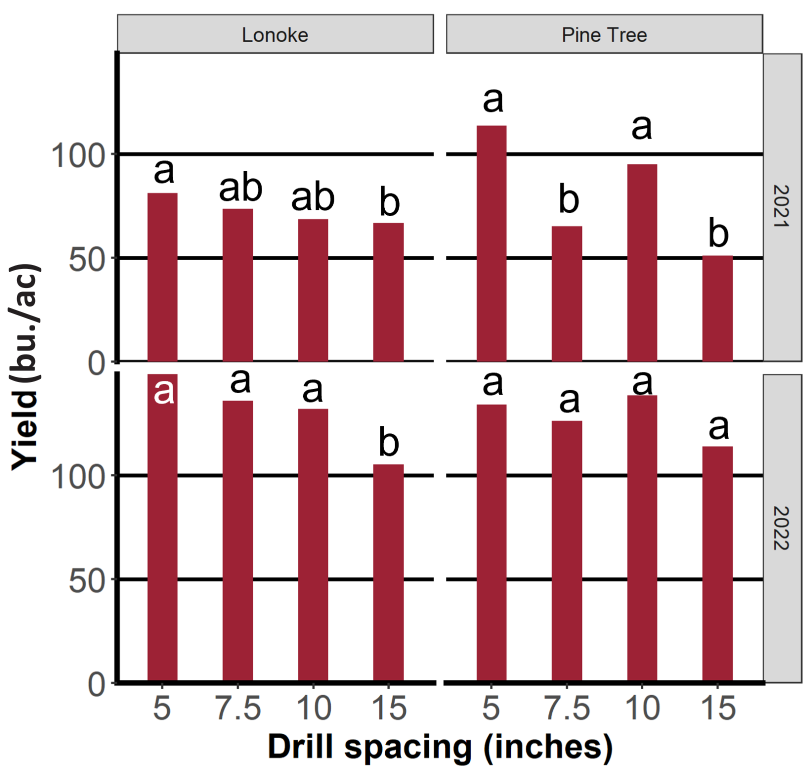

Fig. 6. Rice yield as affected by drill row spacing by year and location. Bars within each panel with the same letter are not different according to Tukey's honestly significant difference (α = 0.05).

Investigating the Response of Glutathione-*S*-Transferase (*GSTs*) Genes in Fenclorim-Coated Rice Under Acetochlor Treatment

F. González-Torralva,[1] J.K. Norsworthy,[1] and T.H. Avent[1]

Abstract

Fenclorim is a safener that has been demonstrated to protect rice (*Oryza sativa* L.) from acetochlor phytotoxicity. However, the contribution of *GSTs* in fenclorim-coated rice under acetochlor treatment remains undescribed. In this research, the gene expression profile of different *GSTs* that could be involved in the response to acetochlor was studied. Results showed that acetochlor caused a different response in the evaluated *GSTs* during the time-course study (24, 48 and 96 h after acetochlor treatment). Overall, *GSTs* response in fenclorim-coated rice remained similar to that found in the controls (≈ 1-fold). However, at 24 h, *GSTF2* was found to be 1.7-fold upregulated in fenclorim-coated rice compared to that with no fenclorim. Response of *GSTs* with no fenclorim tended to increase over time (e.g., *GSTF5*). However, *GSTU16* displayed a null response to acetochlor in either rice seedlings with or without fenclorim. Based on these findings, acetochlor is not causing an upregulation at least in the described *GSTs*, and that could be attributed to different factors.

Introduction

Fenclorim (4, 6-dichloro-2-phenyl-pryrimidine) is a safener developed to protect rice (*Oryza sativa* L.) to chloroacetanilide herbicides (Hu et al., 2020), mainly pretilachlor. However, recent studies have demonstrated that fenclorim can safen rice to acetochlor phytotoxicity (Avent et al., 2023). Acetochlor is a chloroacetamide herbicide that belongs to group 15 (very-long-chain-fatty acid, VLCFA), and works by inhibiting the cell division (early plant development) (Trenkamp et al., 2004). It has been demonstrated that fenclorim can protect from pretilachlor damage by causing an upregulation of genes that are related to detoxification pathway (e.g., *GSTs* and *P450* genes). Glutathione-S-Transferase (*GSTs*) genes and *P450* genes are crucial for xenobiotics detoxification and have been correlated to a quick response to biotic and abiotic stresses. These enzymes have been widely researched for their detoxification ability (Dixon and Edwards, 2010; Sappl et al., 2009). Genes reported to have an upregulation by fenclorim and/or pretilachlor include *CYP71Y83*, *CYP71K14*, *CYP734A2,* and *CYP71D55*, along with *GSTU16* and *GSTF5* (Hu et al., 2020). However, information regarding the role of *GSTs* in fenclorim-coated rice under acetochlor treatment is still unknown.

The objective of this research was to quantify the gene expression of selected *GSTs* in fenclorim-coated rice under acetochlor treatment.

Procedures

Rice Material

Fenclorim-coated Diamond rice seeds with and without fenclorim were used in this research. Rice seeds were planted in circular pots (10 cm in diameter) containing sieved silt loam-field soil consisting of 34% sand, 53% silt, 13% clay, and 1.5% organic matter. Four seeds were planted per pot at 0.5 cm deep, after pots were watered until field capacity. Pots were maintained under greenhouse conditions at 32/22 °C temperature and a photoperiod of 14/10 h day/light regimen. Five days after planting, acetochlor at 0.936 lb ai/ac was sprayed over the planted rice seeds. Herbicide treatment was carried out with an automatic sprayer calibrated to deliver 20 gal/ac.

RNA Extraction and Complementary DNA (cDNA) Synthesis

Tissue of rice seedlings with and without fenclorim was collected at 24, 48, and 96 h after acetochlor application, placed in Eppendorf tubes, and immediately frozen in liquid nitrogen. Total ribonucleic acid (RNA) was extracted using the Monarch Total RNA Miniprep kit (New England Biolabs, Ipswich, Mass., USA) following the manufacturer's directions. RNA was quantified using a nanodrop (Nanodrop 2000c, Thermo Scientific, Waltham, Mass., USA). iScript Reverse Transcription Supermix kit (Bio-Rad Laboratories Inc., Hercules, Calif., USA) was utilized to synthesize the cDNA using 1 µg of RNA as template. The cDNA was diluted 1:4 times with deionized water to be used as a working concentration in subsequent experiments.

Quantitative Polymerase Chain Reactions (qPCRs)

The *GSTs* were selected and pulled out from published literature (Brazier-Hicks et al., 2020, Hu et al., 2020). *Actin* was utilized as a reference gene since its stability has been demonstrated under different conditions (Cao et al., 2013). Primers were designed using the Primer3Plus software (available at https://www.primer3plus.com/). qPCRs comprised a final volume of 10 µL with 5 µL of 2× SsoAdvanced Universal SYBR Green Supermix (Bio-Rad Laboratories Inc., Hercules, California, USA), 0.3 µL of each forward and

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reverse primer at 10 µM concentration, 2.9 µL deionized water and 1.5 µL cDNA. Reactions were run on a CFX Connect Real-Time System (Bio-Rad Laboratories Inc., Hercules, California, USA). Cycling conditions were as follows: 98 °C for 30 s; followed by 40 cycles of 98 °C for 30 s and 61° for 30 s. Dissociation curves were generated at the end of each run to corroborate specific amplification. Finally, quantification cycle (Cq) values were obtained and used to calculate the fold-change expression by using the $2^{-\Delta\Delta Cq}$ formula (Livak and Schmittgen, 2001).

Results and Discussion

Acetochlor treatment caused a different pattern of gene expression among the evaluated *GST* genes. Overall, in fenclorim-coated seedlings treated with acetochlor (F24, F48, F96), gene expression remained similar to that found in the fenclorim-coated control (FCK, 1-fold) see for instance *GSTF5*, *GSTF12*, *GSTL1*, *GSTU16* and *GSTU35* (Fig. 1). *GSTF2* was an exception to the previous statement, where it was found to be upregulated by 1.7-fold at 24 h (F24) compared to seedlings with no fenclorim (NF24).

In general, in seedlings with no fenclorim (NF) under acetochlor treatment, gene expression tended to increase at 48 or 96 h (NF48 and NF96) after herbicide treatment (see for instance *GSTF5* or *GSTU35*). This upregulation was different from their respective counterparts with fenclorim (F) where expression levels remained at approximately 1-fold (e.g., *GSTF5*, *GSTU35*). However, in *GSTU16*, expression levels found in seedlings with no fenclorim (NF) and fenclorim-coated (F) at the different evaluated time points remained mostly at 1-fold, which was the basal expression in both controls (NFCK and FCK, respectively).

It is interesting to note that fenclorim-coated seedling (F) gene expression profiles (except F24 in *GSTF2*) were mostly constant and similar to that found in controls (≈ 1-fold). Explanation of these results would be: a) fenclorim is blocking the contact of acetochlor with seedlings, and thus, there is no response at all in the selected *GSTs*, b) acetochlor is not reaching the seedlings good enough to cause a stress and as a consequence *GSTs* are not being “activated”, and c) involvement of other *GST* or *P450* genes (Hu et al., 2020). Overall, seedlings with no fenclorim (NF) under acetochlor treatment displayed an increase in gene expression suggesting that acetochlor reached those seedlings.

Expression profiles in seedlings with no fenclorim (NF) seem to follow a defined pattern and increase over time. Nonetheless, gene expression patterns in fenclorim-coated seedlings under acetochlor treatment are still unclear. Further experiments are needed to fully understand the role of fenclorim to safen rice seedlings to acetochlor.

Practical Applications

In this research, we have gathered more knowledge about the role of different *GSTs* in fenclorim-coated rice under acetochlor treatment. These results will help in understanding the contribution of *GSTs* when fenclorim is used to safen rice to acetochlor or other chloroacetamide herbicides.

Acknowledgments

Support given during all these years by the Arkansas Rice Research and Promotion Board and the University of Arkansas System Division of Agriculture is greatly acknowledged.

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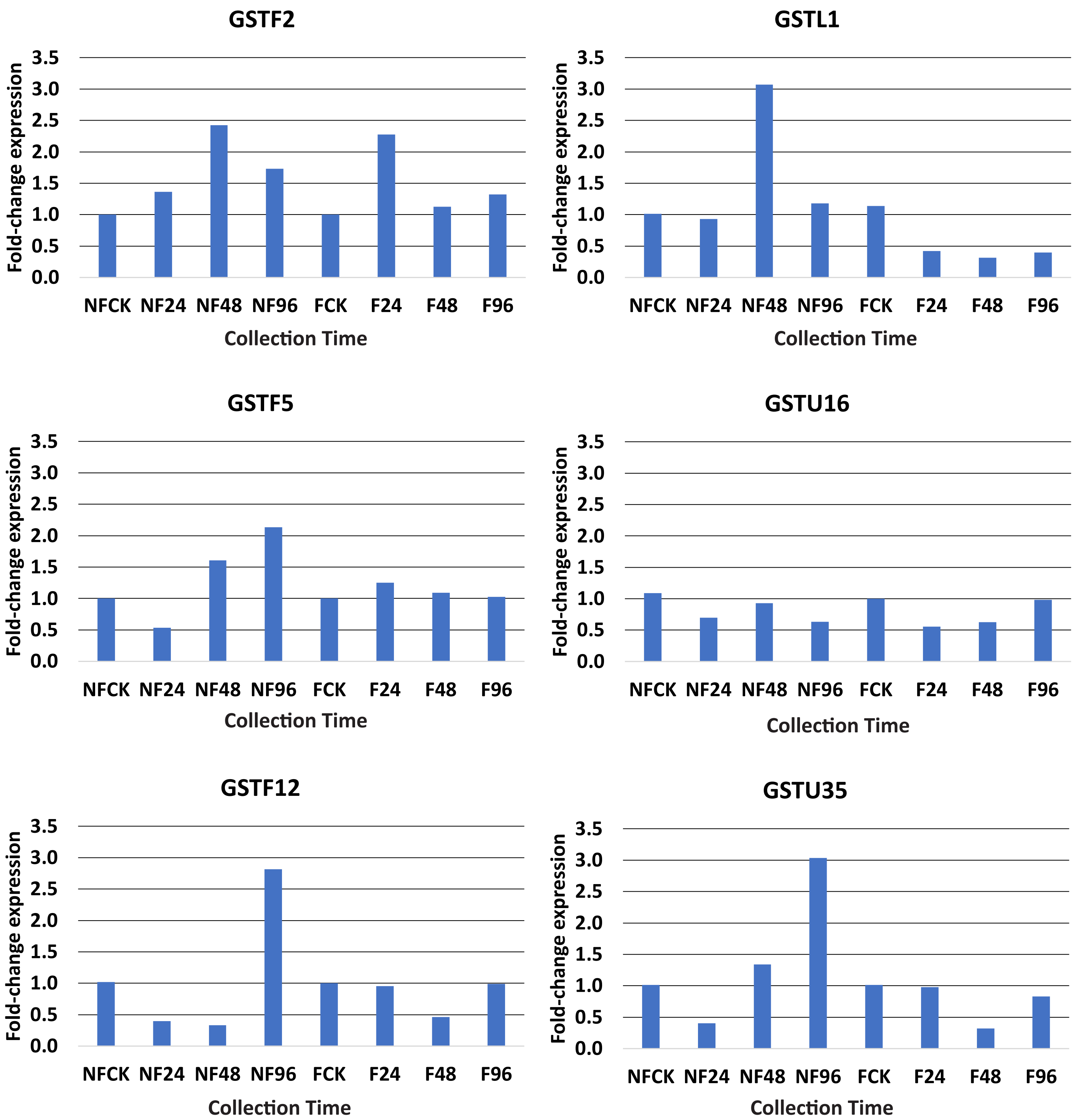

Fig. 1. Gene expression profiles of selected *GSTs* at different collection times. NFCK, no fenclorim control; NF24, NF48, NF96, no fenclorim at 24, 48, and 96 h after acetochlor application, respectively. FCK, fenclorim control; F24, F48, F96, fenclorim at 24, 48, and 96 h after acetochlor application, respectively.

Single Pass Postemergence Herbicide Mixtures for Control of Challenging Grasses in Arkansas Rice

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

Abstract

Based on recent surveys, barnyardgrass [(*Echinochloa crus-galli* (L.) P. Beauv] and Amazon sprangletop [*Diplachne panicoides* (J. Presl) Hitchc.] are considered the most problematic grass weeds in Arkansas furrow-irrigated rice (*Oryza sativa* L.) fields. Without the benefit of established flood conditions to assist in controlling weeds, the utilization of residual herbicides throughout the season is required. In 2022, an experiment was conducted in Tillar, Ark., to determine the most effective one-shot rice herbicide tank-mixtures to control barnyardgrass and Amazon sprangletop in furrow-irrigated rice. Herbicide treatments consisted of Rebel EX, Ricebeaux, and Ricestar HT applied alone or in tank-mixture with Command or RiceOne and Ricestar HT + Postscript + Command applied at the 2-leaf rice stage. At 9 days after application (DAA), Ricebeaux in tank-mixture with RiceOne provided greater than 95% visual control of both grass species. By 17 DAA, herbicide efficacy had decreased from most herbicide treatments; however, Ricebeaux in tank-mixture with RiceOne and Ricestar HT + Postscript + Command continued to provide greater than 88% control of barnyardgrass. When applied alone, Rebel EX, Ricebeaux, and Ricestar HT failed to provide greater than 60% control of either grass species at 17 DAA. At the final evaluation, most herbicide treatments continued to decrease in control of both grasses; however, Ricestar HT + Postscript + Command provided 94% control of barnyardgrass and 91% control of Amazon sprangletop at 22 DAA. These data suggest that the use of multiple residual herbicides and modes of action will be beneficial in controlling these problematic grass weeds in furrow-irrigated rice.

Introduction

Furrow-irrigated rice (*Oryza sativa* L.) acreage has increased significantly with 16.9% of Arkansas rice acres produced in a furrow-irrigated system in 2020 (Hardke, 2020). This is due to furrow-irrigated rice production having advantageous benefits over flooded rice, such as time, labor, and costs. The associated disadvantages with furrow-irrigated rice primarily include a change in weed and insect spectrums to control (Tracy et al. 1993). In a recent survey, Arkansas rice producers and consultants indicated that barnyardgrass [*Echinochloa crus-galli* (L.) P. Beauv] was the most problematic weed species in rice, regardless of the growing environment (Butts et al. 2022). Additionally, Norsworthy et al. 2013 determined that Amazon sprangletop [*Diplachne panicoides* (J. Presl) Hitchc.] was listed among the top weeds of concern in Arkansas rice. The objective of this research was to determine effective herbicide tank-mixtures to control these problematic grass weed species commonly found in Arkansas rice fields.

Procedures

An experiment was conducted at Tillar, Ark., to determine the most effective one-shot rice herbicide tank-mixtures to control barnyardgrass and Amazon sprangletop in furrow-irrigated rice. This experiment was set up as a randomized complete block design with four replications on a silty-clay loam soil in 2022. Rice cultivar RT7521FP was seeded at 30 lb/ac with plot sizes of 6.33 ft by 30 ft. Herbicide treatments included Rebel EX® (penoxsulam plus cyhalofop-butyl) at 0.252 lb ai/ac, Ricebeaux® (propanil plus thiobencarb) at 4.5 lb ai/ac, and Ricestar® HT (fenoxaprop) at 0.109 lb ai/ac, with these herbicides being applied alone or in tank-mixture with Command® (clomazone) at 0.375 lb ai/ac or RiceOne (clomazone plus pendimethalin) at 1.13 lb ai/ac. An additional treatment included Ricestar HT at 0.109 lb ai/ac in tank-mixture with Postscript (imazamox) at 0.039 lb ai/ac + Command at 0.375 lb ai/ac. All herbicide treatments, except for treatments containing Ricebeaux were applied with crop oil concentrate at 1.0% v/v. A nontreated control was also included for comparison. Weed efficacy ratings were taken at 9, 17, and 22 days after the postemergence application. Herbicide treatments were applied at the 2-leaf rice stage and applied with a compressed air pressurized tractor-mounted sprayer at 3.5 mph with a carrier volume of 15 GPA and using Teejet AIXR 11002VP nozzles. Weed efficacy data were subjected to an analysis of variance and means were separated by Fisher's protected least significant difference (α = 0.05).

Results and Discussion

Following treatment applications, initial visual control of barnyardgrass was less than 90% from all treatments, except for Ricebeaux in tank-mixture with RiceOne (93%) at 9 days after application (DAA) (Table 1). Ricebeaux at 4.5 lb ai/ac alone and in tank-mixture with Command at 0.375 lb ai/ac provided comparable control of barnyardgrass to Ricebeaux tank-mixed with RiceOne. Overall greater control of Amazon sprangletop compared

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to barnyardgrass was observed at 9 DAA, with most treatments providing greater than or equal to 90% control (Table 1). Herbicide efficacy had decreased for most treatments by 17 DAA (Table 2). Ricebeaux tank mixed with RiceOne provided the greatest level of control of barnyardgrass (90%) and was comparable to Ricestar HT + Postscript + Command (88%). All herbicide treatments applied without residuals failed to provide greater than 50% control of barnyardgrass at 17 DAA. Ricestar HT + Postscript + Command provided the highest level of control of Amazon sprangletop (94%) at 17 DAA, whereas control had decreased significantly across all other treatments (Table 2). Ricebeaux in tank-mixture with Command continued to provide comparable control of Amazon sprangletop to Ricestar HT + Postscript + Command. By 22 DAA, herbicide efficacy continued to decrease in all treatments except for Ricebeaux tank-mixed with RiceOne and Ricestar HT + Postscript + Command, with 88- and 94% control of barnyardgrass, respectively (Table 3). Rebel EX applied alone failed to provide any control of either grass species at this evaluation timing. No treatment provided greater than 81% control of Amazon sprangletop, except for Ricestar HT + Postscript + Command, which provided 91% control at 22 DAA (Table 3).

Practical Applications

Based on these data, the utilization of soil-residual herbicides in tank-mixture with postemergence grass herbicides is necessary to control barnyardgrass and Amazon sprangletop in furrow-irrigated rice herbicide programs. The inclusion of multiple herbicide modes of action as in the treatments Ricebeaux + RiceOne and Ricestar HT + Postscript + Command were more beneficial in controlling these problematic grass species in addition to preventing the development of herbicide resistance in these grass weeds.

Acknowledgments

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Table 1. Barnyardgrass and Amazon sprangletop visual control at 9 days after application in Tillar, Ark., in 2022.

Treatment(s)	Rate	Application Timing	Visual control: Barnyardgrass	Visual control: Amazon sprangletop
	(lb ai/ac)		-------------------%------------------	
Nontreated control	---		0	0
Rebel EX	0.252	1-3 leaf rice	51	73
Ricebeaux	4.5	1-3 leaf rice	84	91
Ricestar HT	0.109	1-3 leaf rice	40	49
Rebel EX + Command	0.252 + 0.375	1-3 leaf rice	74	90
Rebel EX + RiceOne	0.252 + 1.13	1-3 leaf rice	73	90
Ricebeaux + Command	4.5 + 0.375	1-3 leaf rice	89	94
Ricebeaux + RiceOne	4.5 + 1.13	1-3 leaf rice	93	98
Ricestar HT + Command	0.109 + 0.375	1-3 leaf rice	61	83
Ricestar HT + RiceOne	0.109 + 1.13	1-3 leaf rice	65	78
Ricestar HT + Postscript + Command	0.077 + 0.039 + 0.375	1-3 leaf rice	78	89
LSD (α = 0.05)			10	12

Abbreviations: LSD = least significant difference; lb ai/acre = pounds of active ingredient per acre.

Table 2. Barnyardgrass and Amazon sprangletop visual control at 17 days after application in Tillar, Ark., in 2022.

Treatment(s)	Rate	Application Timing	Visual control: Barnyardgrass	Visual control: Amazon sprangletop
	lb ai/ac		---------------------%---------------------	
Nontreated control	---		0	0
Rebel EX	0.252	1-3 leaf rice	38	24
Ricebeaux	4.5	1-3 leaf rice	50	61
Ricestar HT	0.109	1-3 leaf rice	31	28
Rebel EX + Command	0.252 + 0.375	1-3 leaf rice	68	66
Rebel EX + RiceOne	0.252 + 1.13	1-3 leaf rice	70	68
Ricebeaux + Command	4.5 + 0.375	1-3 leaf rice	78	83
Ricebeaux + RiceOne	4.5 + 1.13	1-3 leaf rice	90	77
Ricestar HT + Command	0.109 + 0.375	1-3 leaf rice	71	71
Ricestar HT + RiceOne	0.109 + 1.13	1-3 leaf rice	66	59
Ricestar HT + Postscript + Command	0.077 + 0.039 + 0.375	1-3 leaf rice	88	94
LSD (α = 0.05)			11	11

Abbreviations: LSD = least significant difference; lb ai/acre = pounds of active ingredient per acre.

Table 3. Barnyardgrass and Amazon sprangletop visual control at 22 days after application in Tillar, Ark., in 2022.

Treatment(s)	Rate	Application Timing	Visual control: Barnyardgrass	Visual control: Amazon sprangletop
	lb ai/ac		----------------------%----------------------	
Nontreated control	---		0	0
Rebel EX	0.252	1-3 leaf rice	0	0
Ricebeaux	4.5	1-3 leaf rice	50	47
Ricestar HT	0.109	1-3 leaf rice	48	43
Rebel EX + Command	0.252 + 0.375	1-3 leaf rice	53	60
Rebel EX + RiceOne	0.252 + 1.13	1-3 leaf rice	58	48
Ricebeaux + Command	4.5 + 0.375	1-3 leaf rice	58	60
Ricebeaux + RiceOne	4.5 + 1.13	1-3 leaf rice	89	81
Ricestar HT + Command	0.109 + 0.375	1-3 leaf rice	65	63
Ricestar HT + RiceOne	0.109 + 1.13	1-3 leaf rice	55	49
Ricestar HT + Postscript + Command	0.077 + 0.039 + 0.375	1-3 leaf rice	94	91
LSD (α = 0.05)			12	15

Abbreviations: LSD = least significant difference; lb ai/acre = pounds of active ingredient per acre.

Effects of Malathion and 4-Chloro-7-Nitrobenzofurazan (NBD-Cl) on Metabolism of Cyhalofop-Butyl (Clincher) in Resistant Barnyardgrass [*Echinochloa crus-galli* (L.) P. Beauv.]

J.I. Hwang,[1] J.K. Norsworthy,[1] T.R. Butts,[2] and L.T. Barber[2]

Abstract

Postemergence management of barnyardgrass [*Echinochloa crus-galli* (L.) P. Beauv] with evolution of resistance to acetyl-CoA carboxylase (ACCase) inhibitors is a challenging task. In a previous study, we confirmed several barnyardgrass accessions resistant metabolically to both the ACCase inhibitor cyhalofop-butyl (CyB; Clincher) and the synthetic auxin herbicide florpyrauxifen-benzyl (Loyant). The current study was performed to investigate effects of malathion (cytochrome P450 inhibitor) and/or 4-chloro-7-nitrobenzofurazan (NBD-Cl; glutathione S-transferase inhibitor) on metabolism of CyB in the resistant barnyardgrass accessions. Both malathion and NBD-Cl were not effective in restoring sensitivity of resistant barnyardgrass accessions to CyB (0.3 lb ai/ac). Rather, treatment with malathion followed by (fb) CyB antagonized the CyB's efficacy. Absorption of CyB in both CyB-susceptible (S) and resistant (R) barnyardgrass accessions was not influenced by malathion pretreatment. The consumption of CyB in S and R accessions decreased 1.5- to 10.5 times by pretreatment of malathion. However, production of cyhalofop-acid, the active herbicide form, was similar between treatments with CyB alone (1.8% to 17.3%) and treatments with malathion fb CyB (1.0% to 19.3%). Conclusively, malathion can antagonize CyB in barnyardgrass by contributing to reduced metabolism of CyB but not to its conversion to cyhalofop-acid.

Introduction

Cyhalofop-butyl (CyB), an acetyl coenzyme A carboxylase (ACCase) inhibitor, is used to control Poaceae weed species like barnyardgrass [*Echinochloa crus-galli* (L.) P. Beauv]. However, repeated uses of CyB or other inhibitors with the same mode of action have led to the evolution of resistance to the herbicide in barnyardgrass (Yang et al., 2021; Butts et al., 2022). The evolution of herbicide resistance in weeds can be caused by either target-site resistance (TSR) mechanisms provoking genetic alteration of herbicide target-site proteins or non-target-site resistance (NTSR) mechanisms changing herbicide absorption, translocation, and/or metabolism (Ghanizadeh and Harrington, 2017). The improved activity of plant detoxification enzymes such as cytochrome P450 (P450), glutathione S-transferase (GST), and glucosyltransferases can lead to metabolic resistance evolution in weeds (Ghanizadeh and Harrington, 2017; Shyam et al., 2021). Evaluating restoration of herbicide sensitivity in resistant weeds following pretreatment of malathion (P450 inhibitor) or 4-chloro-7-nitrobenzofurazan (NBD-Cl; GST inhibitor) is frequently used to verify whether herbicide resistance is evolved by enhanced metabolism and what types of detoxification enzymes in plants are involved (Fang et al., 2019; Strom et al., 2020; Shyam et al., 2021). The current study evaluated effects of malathion and NBD-Cl on reversing CyB resistance in resistant barnyardgrass biotypes. Subsequently, experiments were conducted to evaluate absorption and metabolism of CyB in the resistant biotypes following pretreatment with malathion or NBD-Cl.

Procedures

Along with susceptible (S) barnyardgrass, two resistant (R1 and R2) barnyardgrass biotypes confirmed with multiple resistance to both CyB (R/S ratios = 7 and 21, respectively) and the synthetic auxin herbicide florpyrauxifen-benzyl (R/S ratios = 50 and 150, respectively) in a previous study were used in the present study (Hwang et al., 2022). Seeds of R biotypes were harvested from plant entities that survived an application of CyB (Clincher SF, Corteva Agriscience, Ind., USA) at the labeled rate (0.3 lb ai/ac).

Metabolism inhibition experiments were performed by spraying malathion (0.89 lb ai/ac; Spectracide®, Spectrum Brands Holdings Inc., Madison, Wis., USA) and NBD-Cl (NBD-Cl; 0.24 lb ai/ac; Millipore Sigma, Burlington, Mass., USA) on four-leaf barnyardgrass seedlings 2 h and 48 h before CyB application, respectively. The aboveground tissues of the sprayed plants were evaluated for dry biomass reductions 28 d after application of CyB at the labeled rate. Absorption and metabolism of CyB in S and R barnyardgrass biotypes were also evaluated. At the four-leaf stage, seedlings of each barnyardgrass biotype were pre-treated with malathion and NBD-Cl using the same aforementioned method and then sprayed with the commercial product of CyB (0.3 lb ai/ac). Plant samples for the absorption test were additionally treated with carbon-14-labeled CyB ([^{14}C]-CyB; Corteva Agriscience™, Indianapolis, Ind., USA); briefly, the second true leaf of the sprayed plants was treated with 2.0 kBq of [^{14}C]-CyB (1.0 kBq/µL × 1.0 µL/droplet × 2 droplets/plant). All treated

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plants for absorption and metabolism experiments were grown in a growth chamber with 86/77 °F day/night temperatures and collected 6, 12, 24, and 48 h after [^{14}C]-herbicide treatment. For the [^{14}C]-CyB-treated plants, the treated leaf was rinsed with 5 mL methanol. The rinsate was gathered in a vial for later analysis. The rinsed plants were subjected to dissection into three sections (the treated leaf, untreated aboveground tissue, and belowground tissue) and then combustion using a biological oxidizer. The rinsate and oxidized tissue samples were analyzed using a liquid scintillation counter, and the analytical results were reconsidered to calculate absorption magnitudes of [^{14}C]-CyB in barnyardgrass samples. Some of the rinsed plant samples were used to obtain radiographic images. For plant samples collected for metabolism experiments, the plant surface was rinsed sequentially with tap water and 10 mL methanol. Subsequently, the whole plant tissue without dissection was used for analysis of the parent CyB and an active form metabolite cyhalofop-acid (CyA). A high-performance liquid chromatography−diode array detector (HPLC−DAD) was used for the chemical quantification.

All statistical analysis was conducted using Predictive Analytics Software (PASW) Statistics 18 (International Business Machines Co., Armonk, N.Y., USA). A one-way analysis of variance with Tukey's honestly significant difference post hoc test ($\alpha = 0.05$) was applied to evaluate significant differences in analytical results between S and R biotypes at each sampling time. Additionally, a paired *t*-test was done to show significant differences between treatments with and without malathion ($\alpha = 0.05$).

Results and Discussion

While barnyardgrass biomass reduction by treatment with NBD-Cl fb CyB was similar with that by treatment with CyB alone ($P > 0.05$), treatment with malathion fb CyB mitigated the biomass reduction of S (15%) and R (−56% to −6%) biotypes or rather increased the biomass over the nontreated barnyardgrass (Fig. 1). These results would imply that malathion can antagonize CyB in barnyardgrass as well as help the weed better grow under the presence of CyB.

The foliar absorption following treatment with CyB alone was similar for S (93.7% to 99.2%) and R (89.3% to 98.9%) biotypes ($P > 0.05$; Fig. 2). Likewise, differences were not observed in absorption between S (86.8% to 97.5%) and R (83.7% to 97.8%) biotypes following treatment with malathion fb CyB ($P > 0.05$). Radiographs of barnyardgrass plants collected at the end of the 48-h study did not visually show differences between S and R biotypes and between treatments with CyB alone and with malathion fb CyB (Fig. 3). Thus, absorption and translocation of CyB were not associated with mechanisms causing resistance and malathion antagonism to CyB in barnyardgrass. Over the entire study period, residues of CyB in S and R biotypes were 1.5 to 10.5 times greater in the treatment with malathion fb CyB (2.8% to 15.4%) than in the treatment with CyB alone (0.0% to 2.7%) ($P < 0.05$) (Fig. 4). Contrary to the CyB residue results, residues of the active herbicide form CyA were similar between treatments with CyB alone (1.8% to 17.3%) and with malathion fb CyB (1.0% to 19.3%) ($P > 0.05$). The constant CyA residue against the reduced CyB consumption elucidates that P450-based metabolism of CyB in barnyardgrass was likely to involve pathways bypassing or mitigating conversion of CyB to CyA, by which CyB resistance in barnyardgrass was not reversed by malathion.

Practical Applications

Results of this study are useful for finding solutions to mitigate or overcome barnyardgrass resistance to CyB and to obtain inspiration for the development of new herbicide actives.

Acknowledgments

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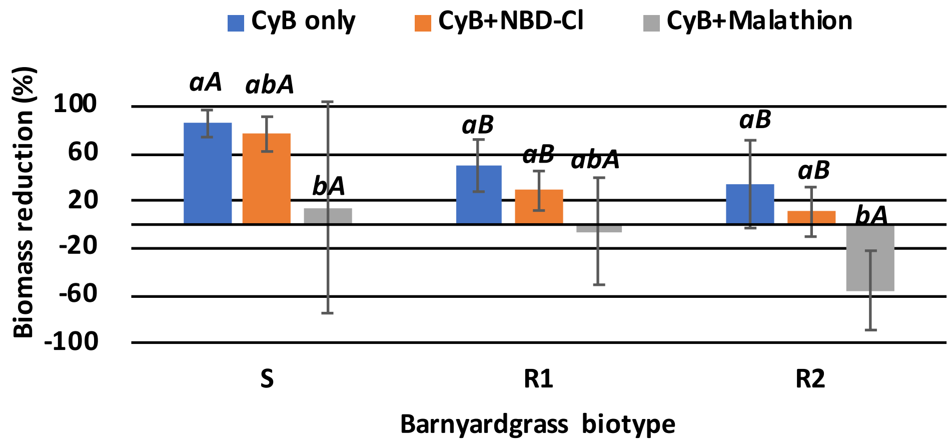

Fig. 1. Biomass reduction of susceptible (S) and two resistant (R1 and R2) barnyardgrass biotypes by treatment of malathion or NBD-Cl followed by cyhalofop-butyl (CyB). Error bars represent standard deviations (*n* = 9 pots including 3 plants for each). A Post-Hoc analysis using Tukey's honestly significant difference test method was conducted to represent differences between treatments of each barnyardgrass biotype (different italic lowercase letters) and between S and R biotypes (different italic capital letters) (*P* < 0.05).

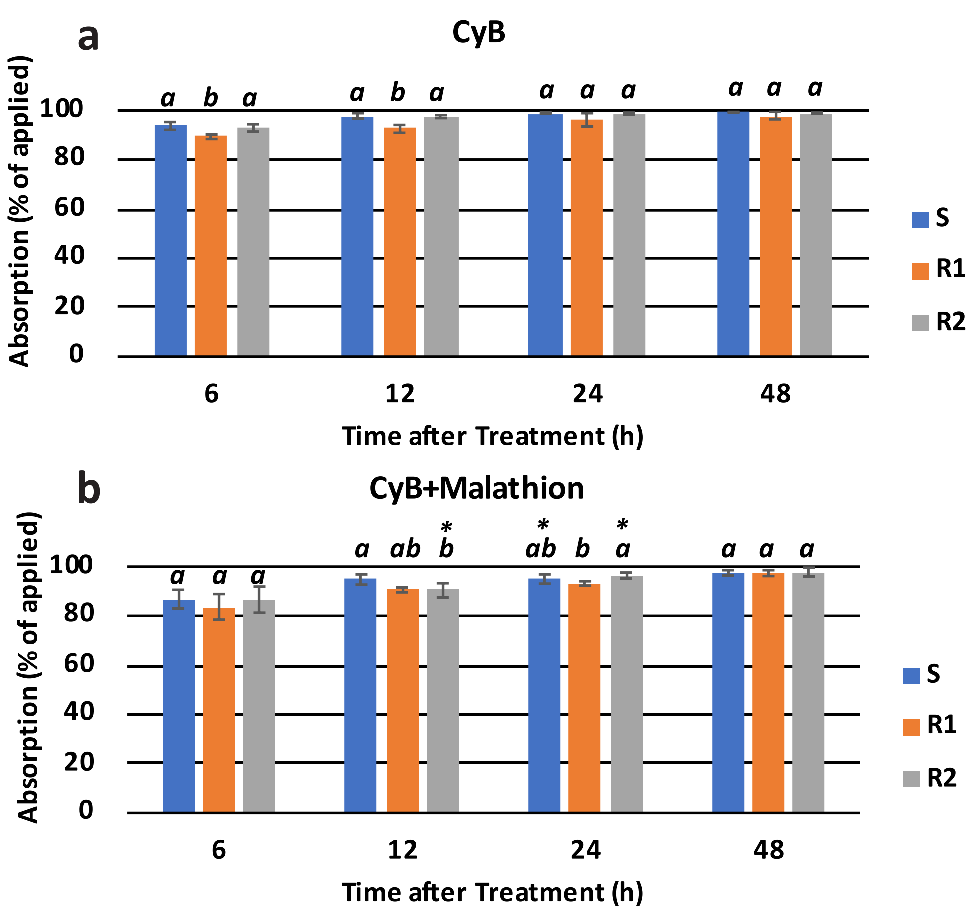

Fig. 2. Foliar absorption of [^{14}C]-cyhalofop-butyl (CyB) by susceptible (S) and two resistant (R1 and R2) barnyardgrass biotypes following treatment of CyB alone (a) or malathion followed by CyB (b). Error bars represent standard deviations to mean values (*n* = 6). An asterisk mark indicates differences between treatments with and without malathion based on a paired *t*-test (*P* < 0.05). A Post-Hoc analysis using Tukey's honestly significant difference test method was conducted to represent differences between S and R biotypes (different italic lowercase letters) (*P* < 0.05).

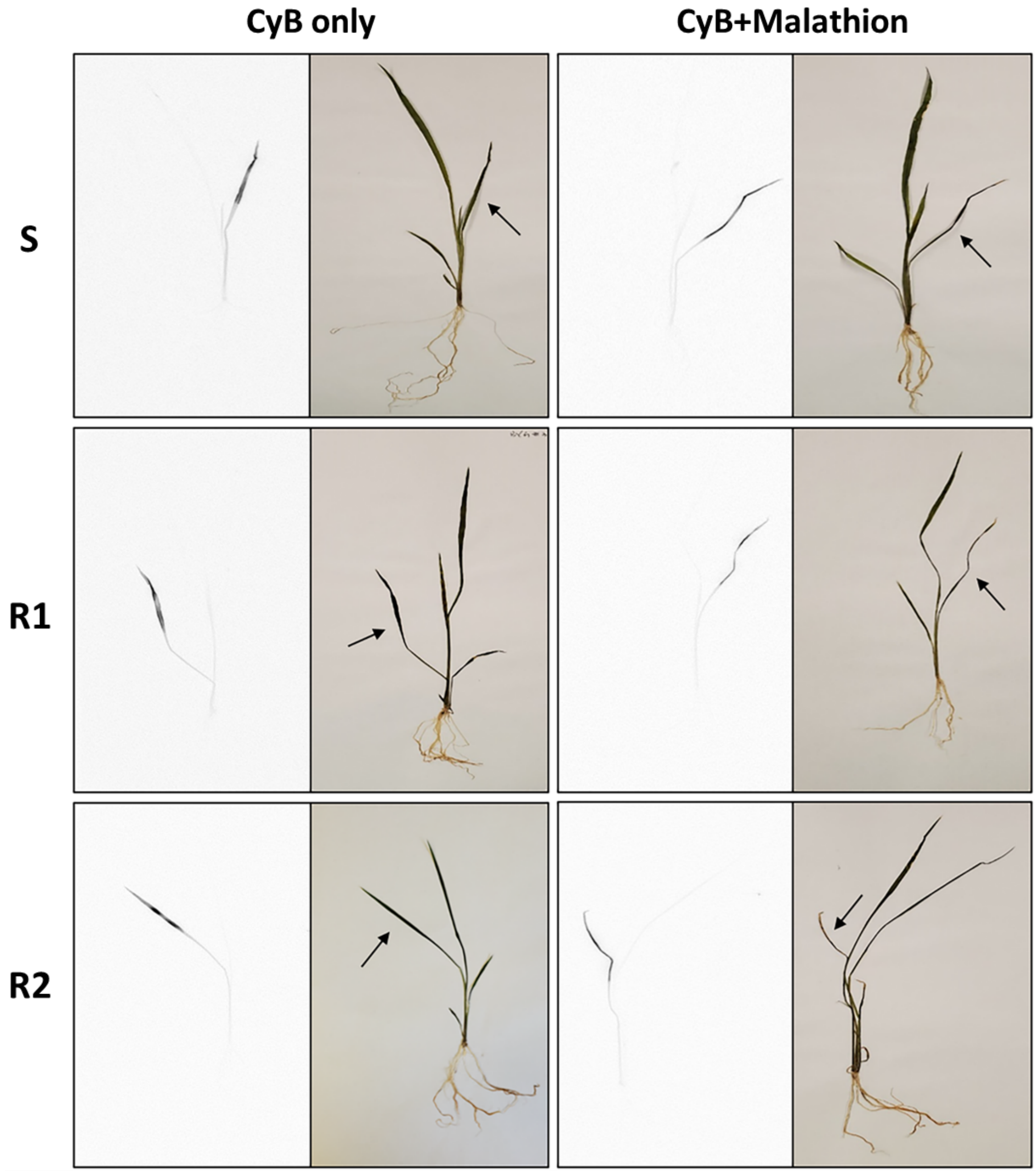

Fig. 3. Radiographs of one susceptible (S) and two resistant (R1 and R2) barnyardgrass biotypes collected 48 h after treatments of cyhalofop-butyl (CyB) alone or malathion followed by CyB.

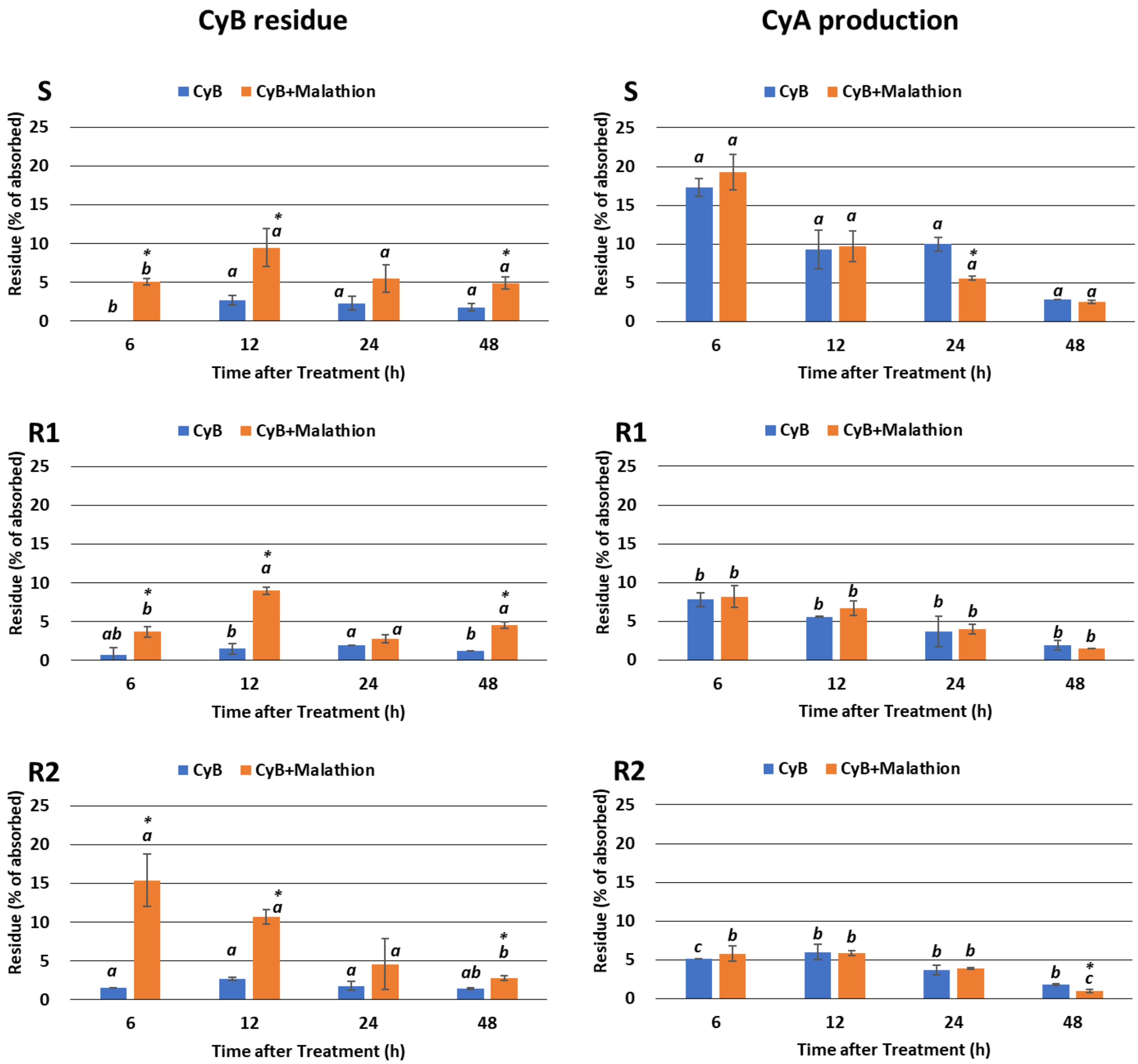

Fig. 4. Residues of cyhalofop-butyl (CyB) and -acid (CyA) in susceptible (S) and two resistant (R1 and R2) barnyardgrass biotypes following treatment of CyB alone or malathion followed by CyB. Error bars represent standard deviations (*n* = 6). An asterisk mark indicates differences between treatments with and without malathion based on a paired *t*-test (*P* < 0.05). A Post-Hoc analysis using Tukey's honestly significant difference test method was conducted to represent differences between S and R biotypes (different italic lowercase letters) (*P* < 0.05).

Interference of Palmer Amaranth in Furrow-Irrigated Rice: What is the Area of Influence?

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Abstract

Arkansas rice (*Oryza sativa* L.) producers face challenges when transitioning to a furrow-irrigated rice (FIR) system, which lacks a continual flood to prevent weed emergence. The lack of a continual flood allows Palmer amaranth [*Amaranthus palmeri* (S.) Wats.] emergence throughout most of the growing season and creates an environment conducive for growth. The presence of Palmer amaranth in a FIR system may result in reduced rice yields and a greater need for additional herbicide applications. A field trial was conducted at the Milo J. Shult Agricultural Research and Extension Center in Fayetteville, Ark., during the 2022 growing season to assess the impact of Palmer amaranth on FIR. Newly emerged Palmer amaranth plants were marked every 7 days, beginning 1 week prior to rice emergence through 4 weeks after rice emergence. Palmer amaranth biomass decreased by 1.5 oz, on average, every 7 days that the emergence of the weed was delayed relative to rice. At 2 weeks after rice emergence and beyond, most Palmer amaranth plants failed to survive until rice harvest. Averaged over emergence times, female plants weighed more than male plants, which resulted in greater interference with rice for limited resources. Female Palmer amaranth plants that emerged one week prior to the emergence of rice produced 270,000 seeds per plant while Palmer amaranth plants that emerged the week after rice produced 11,000 seeds per plant. Palmer amaranth plants that emerged 1 week prior to rice reduced rough rice yield by 60% at 6 inches from the weed. These results show that Palmer amaranth emergence timing is a critical factor influencing rough rice yield potential, Palmer amaranth seed production, and Palmer amaranth biomass.

Introduction

In Arkansas, rice (*Oryza sativa* L.) is traditionally grown in a continuous flood, but furrow-irrigated rice (FIR) acres are increasing (Barber et al., 2020). With the adoption of a FIR system, the lack of a continual flood allows for weed emergence through the entire growing season (Bagavathiannan et al., 2011). Palmer amaranth [*Amaranthus palmeri* (S.) Wats.] is the 5th most problematic weed in flooded rice, but the 2nd most problematic weed in a FIR system (Butts et al., 2022). The innate ability of Palmer amaranth to produce a large number of seeds and hybridize with other *Amaranthus* species allows for heavy infestation across a field rapidly (Keeley et al., 1987; Norsworthy et al., 2014). Palmer amaranth in the United States (U.S.) is resistant to nine different modes of action (MOA) (Heap, 2023). With herbicide resistance being widespread and the ability of Palmer amaranth to compete in a FIR system, this weed has the potential to negatively affect rice yields. Palmer amaranth plants that emerge simultaneously with corn (*Zea mays* L.), have reduced yields by 91% (Massinga et al., 2001), which suggests that Palmer amaranth time of emergence would be associated with rice yield loss.

Procedures

A field experiment was conducted in 2022 at the Milo J. Shult Agricultural Research and Extension Center, in Fayetteville, Ark., to determine the relationship between Palmer amaranth time of emergence and Palmer amaranth seed production, biomass, and rough rice yields in a FIR system. A hybrid rice cultivar (RT 7301) was drill-seeded at 11 seeds/ft of row on a 7.5-in. width row, and the trial was irrigated using standard FIR methods. Clomazone was applied across the experimental area preemergence (PRE) at 0.3 lb ai/ac. Ten Cotyledon stage Palmer amaranth plants were randomly marked each week starting at one week prior to rice emergence through four weeks after rice emergence. In order to help mitigate competition from adjacent weeds, all marked Palmer amaranth plants were a minimum 8 ft apart. Additionally, desired Palmer amaranth plants were covered while the trial was over sprayed with herbicides to remove undesirable weeds. All Palmer amaranth heights and aboveground biomass of surviving plants were collected at rice harvest. Seed production was determined for each Palmer amaranth plant by counting 200 seeds from three plants at each emergence timing. The average weight of 200 seeds was then used to calculate the seed production for each corresponding emergence period. At each marked plant, rough rice yield was collected using hand-held rice knives and a ladder made out of polyvinyl chloride (PVC) pipe with dimensions 1 ft wide by 1 ft long per quadrat that totaled 8 feet long. Yields were collected in each individual quadrat in two directions to assess yield as a function of distance from each Palmer amaranth plant. All data were analyzed using JMP Pro v. 16.2 (SAS Institute, Inc., Cary, N.C.). Palmer amaranth seed production by biomass was linearly regressed. A logistic 3 parameter (L3P) curve was utilized to determine the relationship between yield and distance to Palmer amaranth plants. The two different directions for each

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plant were pooled and separate models were built for each week of emergence. Inverse predictions based on each model were utilized to determine Palmer amaranth's influence on rough rice yield. All other data were subjected to analysis of variance, and means were separated using Fisher's protected least significant difference using an alpha value of 0.05.

Results and Discussion

Palmer amaranth time of emergence influenced its biomass and seed production. Palmer amaranth biomass decreased from 10.1 to 1.0 oz as its emergence was delayed from 1 week prior to the emergence of the crop to 1 week after the crop, respectively, resulting in a 90% reduction in biomass (Fig. 1). Likewise, as Palmer amaranth emergence was delayed, seed production was reduced by 96% when comparing plants that emerged one week prior to rice to those that emerged one week after rice (Fig. 2). There was a positive relationship between Palmer amaranth biomass and Palmer amaranth seed production (data not shown), which is supported by previous literature finding a strong correlation between the biomass of the weed and number of seed produced in soybean production systems (Schwartz et al., 2016). While a significant decrease in seed production is favorable, the amount of seed present at 1 week after the emergence of the rice crop still poses the potential for abundant weed seed carry-over into the soil seedbank for the following year.

Additionally, there was rice yield loss as a function of distance from Palmer amaranth plants for each evaluated time of emergence. Palmer amaranth that emerged two weeks after rice emergence failed to survive the growing season. Palmer amaranth that emerged 1 week prior to the emergence of the crop reduced yield by 92%, 81%, 60%, 35%, and 16% at distances of 0, 3, 6, 9, and 12 in. from the weed (Fig. 3). At distances of 0, 3, 6, 9, and 12 in. from the plant, Palmer amaranth that emerged with the crop reduced rice yields by 86%, 76%, 63%, 47%, and 32%, respectively (Fig. 3). Yield loss was reduced when Palmer amaranth emerged 1 week after the emergence of the crop, considering the highest yield loss was 51% at 0 in. away from the weed (Fig. 3). For all emergence timings, the established rice in the immediate area (0–6 in.) surrounding the weed had yield losses greater than 10%; however, maximum yield potential was not achieved until 42 in. from the Palmer amaranth plants. These findings lead to the conclusion that Palmer amaranth's time of emergence is a critical factor influencing rough rice yields.

Practical Applications

When attempting to control Palmer amaranth in FIR, using a zero-tolerance approach is crucial for maximizing rough rice yields. Allowing even a few Palmer amaranth plants to survive until harvest can have detrimental effects, like weed seed dispersal. Producers should be aware of the potential seed production from Palmer amaranth escapes at harvest, and the impact that the weeds will have on the soil seed bank. Applying residual herbicides, such as pendimethalin and saflufenacil, would prove beneficial by delaying Palmer amaranth emergence to reduce potential rice yield loss and Palmer amaranth biomass and seed production.

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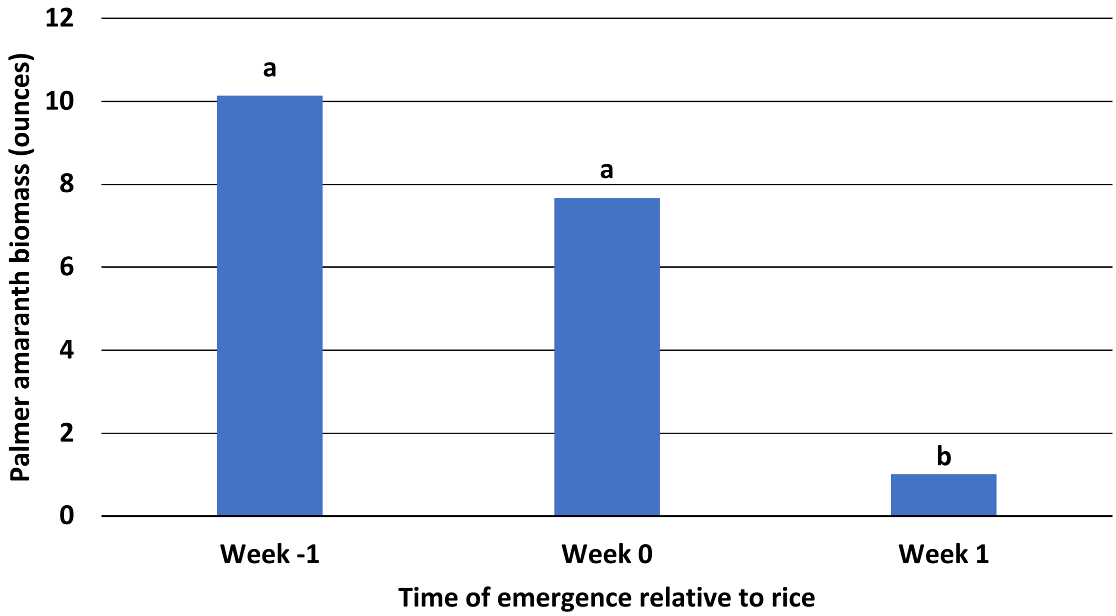

Fig. 1. Influence of Palmer amaranth emergence on biomass in Fayetteville, Arkansas, 2022. Treatments with the same lowercase letter are not different according to Fisher's protected least significant difference at α = 0.05.

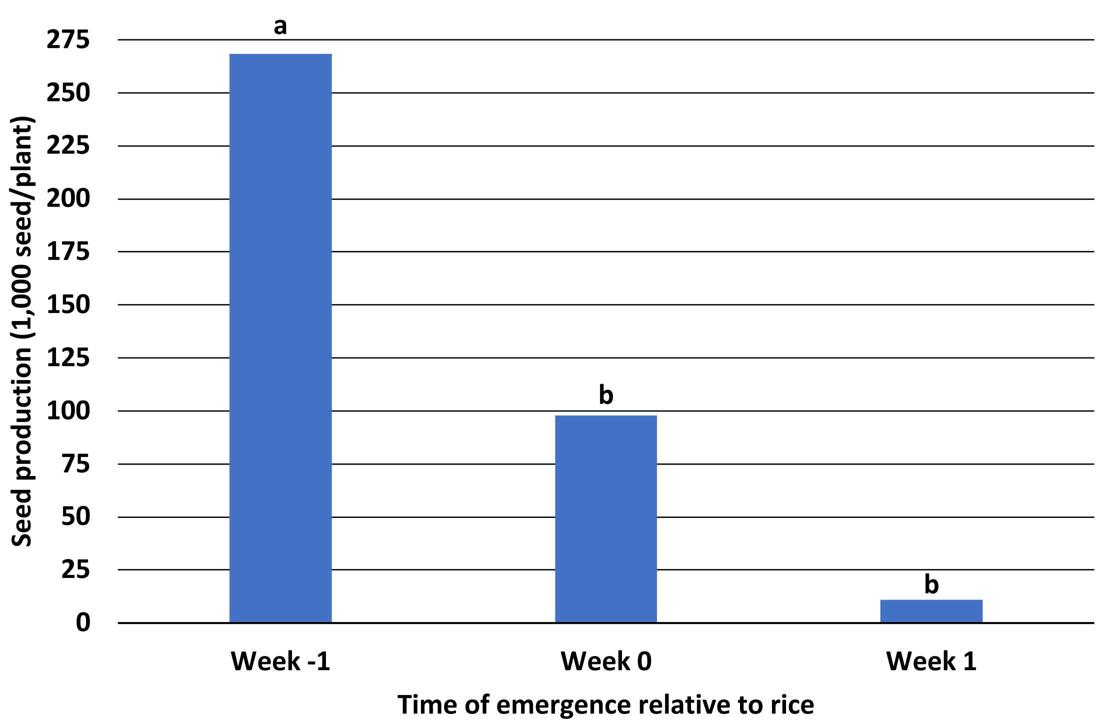

Fig. 2. Influence of Palmer amaranth emergence on seed production in Fayetteville, Arkansas, 2022. Treatments with the same lowercase letter are not different according to Fisher's protected least significant difference at α = 0.05.

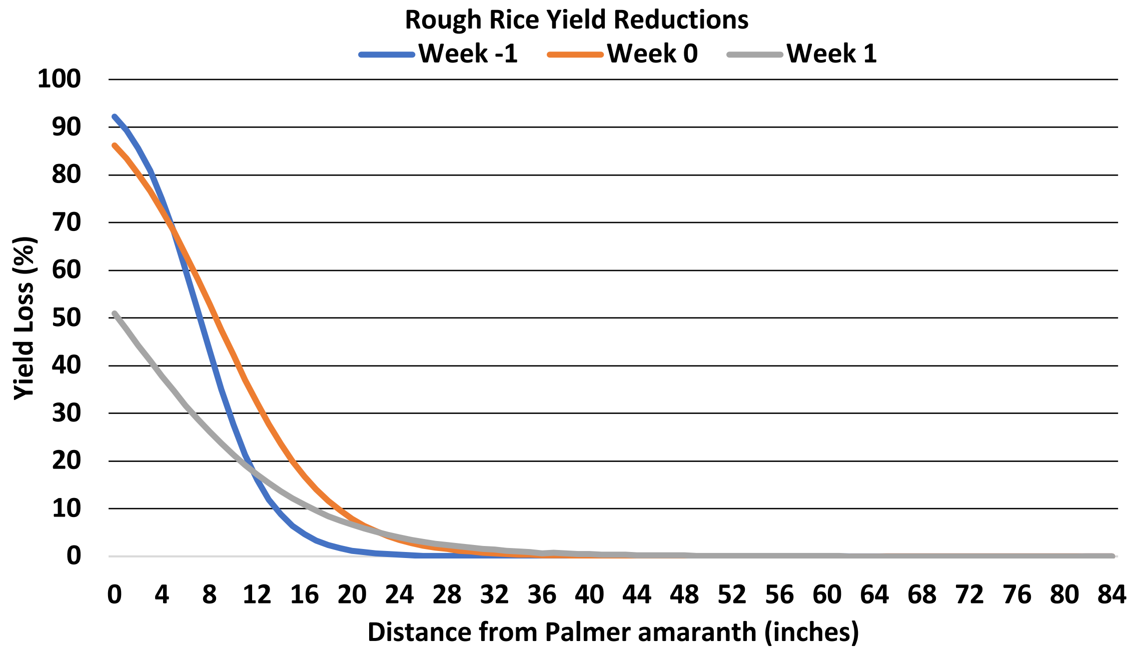

Fig. 3. Rough rice yield loss (%) as a function of distance from Palmer amaranth in Fayetteville, Arkansas, 2022.

Herbicide-Coated Urea Efficacy in United States Mid-South Rice

K.B.J. Kouame,[1] T.R. Butts,[1] B.M. Davis,[1] L.M. Collie,[1] T.W. Dillon,[1] N.H. Reed,[2] J.K. Norsworthy,[2] and L.T. Barber[1]

Abstract

Field experiments were conducted in 2022 at the University of Arkansas Pine Bluff Small Farm Outreach Center near Lonoke, Ark., to evaluate the impact of coating fertilizer with herbicides on weed control efficacy. The first study used three herbicide programs [florpyrauxifen-benzyl (Loyant), a premixture of florpyrauxifen-benzyl + penoxsulam (Novixid), and a mixture of halosulfuron (Permit) + florpyrauxifen-benzyl (Loyant)] applied either as directly coated on urea or as a foliar spray application following urea application, leading to a total of six treatments. Urea (46%), Loyant, Novixid, and Permit were applied at 68.96, 0.03, 0.06, and 0.01 lb ai/ac, respectively. A nontreated control that received an application of urea was also included for weed control evaluation purposes. In a second study, the effect of coating urea with the 4-hydroxyphenylpyruvate dioxygenase-(HPPD-) inhibiting herbicide benzobicyclon (Rogue) was evaluated for weed control. Benzobicyclon sprayed versus coated on urea was applied preflood, flood or post-flood (2 weeks after flood treatment) at 0.34 lb ai/ac. In the first study, barnyardgrass [*Echinochloa crus-galli* (L.) P. Beauv.], rice flatsedge (*Cyperus iria* L.), and yellow nutsedge (*Cyperus esculentus* L.) control were affected by treatments at 7, 14, and 22 days after application (DAA), while hemp sesbania [*Sesbania herbacea* (Mill.) McVaugh] control was affected only at 7 DAA. In most cases, Novixid sprayed foliarly and Novixid-coated urea provided near similar levels of control of barnyardgrass, rice flatsedge, yellow nutsedge, and hemp sesbania. In the second study, hemp sesbania and sprangletop (*Diplachne* spp) control were numerically improved with Rogue applied at flood compared to the other application timings. Also, Rogue-coated on urea at flood provided numerically greater control of both weeds, 15 and 29 days after flood, than did the herbicide when sprayed. As a result, Novixid-coated and Rogue-coated fertilizers may be viable options to maintain high levels of weed control on some of the most problematic Arkansas rice weeds while mitigating off-target herbicide movement.

Introduction

In Arkansas, barnyardgrass [*Echinochloa crus-galli* (L.) P. Beauv.], sedge spp. (*Cyperus* spp), sprangletop spp. (*Diplachne* spp), and hemp sesbania [*Sesbania herbacea* (Mill.) McVaugh] are consistently perceived to be among the most problematic weeds in flooded rice (Butts et al., 2022b). Most of these weeds have evolved resistance to herbicides of several mode-of-action (Heap, 2023). In the same survey, 78% of respondents reported high concern with herbicide-resistant weeds (Butts et al., 2022b). Consequently, there is a crucial need to design and implement an integrated weed management approach in these complex and dynamic weed communities (Norsworthy et al., 2012). Using multiple herbicide modes-of-action (MOAs) effectively against these troublesome weeds is one of the best management practices recommended in the scientific literature (Norsworthy et al., 2012). However, the use of auxin mimic herbicides such as florpyrauxifen-benzyl to control these weeds has raised multiple herbicide drift injury concerns to neighboring sensitive vegetation and crops (Butts et al., 2022a). Therefore, strategies that can help maintain an effective level of weed control while mitigating herbicide drift concerns are essential. Understanding the impact of fertilizer-coating with different herbicides on weed control can improve herbicide application decisions. The objective of this research was to evaluate the efficacy of various rice herbicides coated on urea compared to foliar spray applications on problematic rice weed species.

Procedures

Field experiments were conducted in 2022 at the University of Arkansas at Pine Bluff Small Farm Outreach Center near Lonoke, Ark. A first study, consisting of three herbicide programs [florpyrauxifen-benzyl (Loyant), a premixture of florpyrauxifen-benzyl + penoxsulam (Novixid), and a mixture of halosulfuron (Permit) + florpyrauxifen-benzyl (Loyant)], investigated their applications either as directly coated on urea or as a foliar spray application following urea application, leading to a total of six treatments. Urea (46%), Loyant, Novixid, and Permit were applied at 68.96, 0.03, 0.06, and 0.01 lb ai/ac, respectively. A randomized complete block design was used with three replications. The experimental unit was 10 ft wide by 25 ft long, and herbicide applications were accomplished using sprayers calibrated to deliver 10 GPA with AI110015 nozzles. A nontreated control that received an application of urea was also included for weed control evaluation purposes. In a second study, the effect of coating urea with

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the 4-hydroxyphenylpyruvate dioxygenase-(HPPD-) inhibiting herbicide benzobicyclon (Rogue) was evaluated for weed control in a demonstration trial with 10 ft wide by 50 ft long plots. Rogue sprayed at 15 GPA with AI110015 nozzles versus coated on urea was applied preflood, flood (within 1 week after establishment), or post-flood (2 weeks after flood application timing) at 0.34 lb ai/ac. In the first study, barnyardgrass, rice flatsedge (Cyperus iria L.), yellow nutsedge (*Cyperus esculentus* L.), and hemp sesbania control were visually evaluated 7, 14, and 22 days after application (DAA). Hemp sesbania and sprangletop control were visually evaluated 15 and 29 days after the flood application timing in the Rogue study. Whenever possible, visual weed control data were subjected to analysis of variance using the GLIMMIX procedure in SAS v. 9.4 (SAS Institute Inc, Cary, N.C.) assuming a beta distribution (Gbur et al., 2012) and treatment means were separated using Tukey's honestly significant difference ($\alpha = 0.1$).

Results and Discussion

Data analysis revealed a significant impact of treatments on barnyardgrass, rice flatsedge, and yellow nutsedge visual control at 7, 14, and 22 days after application (DAA) ($P < 0.1$) (Table 1). A significant impact of the treatments for hemp sesbania control ($P < 0.1$) occurred only at 7 DAA, but not at 14 and 22 DAA ($P > 0.1$). For barnyardgrass, rice flatsedge, and yellow nutsedge control evaluated in this research and the three timings (7, 14, and 22 DAA), a foliar spray application of Novixid + MSO (premixture of florpyrauxifen-benzyl + penoxsulam) provided the greatest control (Table 1). Generally, this herbicide program provided > 90% for all species, indicating the excellent weed control level achieved with its use. Also, Novixid applied as directly coated on urea provided similar levels of barnyardgrass control, at 7 and 14 DAA, to that provided by the foliar spray application of Novixid + MSO. However, at 22 DAA the control level achieved by the application of Novixid as directly coated on urea was less than that provided by the foliar spray application of Novixid + MSO but better than that provided by the application of Loyant directly coated on urea, Permit + Loyant + COC directly coated on urea, and the foliar spray application of Permit + Loyant + COC. Permit + Loyant + COC directly coated on urea did not provide any control of barnyardgrass. Similarly, poor control was provided by applying Loyant directly coated on urea. These two programs should only be recommended if barnyardgrass is not a weed species of concern at this application timing. In Arkansas, growers failed to control barnyardgrass 44% of the time with their first postemergence herbicide in 2020. The average population of this weed was estimated between 0.2 to 1 plant ft^{-2} by 41% of survey respondents at the 2020 harvest. The annual average cost of herbicides for rice weed control was \$108 per acre, with barnyardgrass accounting for 81% of the total cost (Butts et al., 2022b). Therefore, herbicide programs that improve the control of this problematic weed are needed. Also, in most cases, Novixid applied directly coated on urea provided near similar levels of control of rice flatsedge, yellow nutsedge, and hemp sesbania as provided by the foliar spray application of Novixid + MSO.

In the second study with Rogue, hemp sesbania and sprangletop spp. control were numerically improved with herbicide programs applied at flood (Fig. 1). Also, the Rogue coated on urea at flood provided numerically greater control of both weeds, 15 and 29 days after flood, than did the herbicide when sprayed.

Practical Applications

Novixid-coated and Rogue-coated fertilizers may be viable options to maintain high levels of weed control on some of the most problematic Arkansas rice weeds while mitigating off-target herbicide movement potential. Additional research is needed to evaluate other problematic weed species, fertilizer types, and timings of applications to solidify herbicide-coated recommendations.

Acknowledgments

This research was funded by the Arkansas Rice Checkoff Program, administered by the Arkansas Rice Research and Promotion Board. Support was also provided by the University of Arkansas System Division of Agriculture.

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Table 1. Barnyardgrass [*Echinochloa crus-galli* (L.) P. Beauv.] (BYG), rice flatsedge (*Cyperus iria* L.) (RFLA), yellow nutsedge (*Cyperus esculentus* L.) (YNUT), and hemp sesbania [*Sesbania herbacea* (Mill.) McVaugh] (HSES) control during field experiments conducted in 2022 at the University of Arkansas at Pine Bluff Small Farm Outreach Center near Lonoke, Ark., to evaluate the impact of coating fertilizer with herbicides on weed control efficacy.†

	BYG			RFLA			YNUT			HSES		
	Days after treatment			Days after treatment			Days after treatment			Days after treatment		
Treatment	**7**	**14**	**22**	**7**	**14**	**22**	**7**	**14**	**22**	**7**	**14**	**22**
	--------------------% control--------------------											
Loyant + Urea	0 c	40 c	45 c	10 c	50 c	57 c	0 d	20 d	37 c	50 c	93 a	100 a
Novixid + Urea	77 a	80 ab	77 b	83 a	87 b	87 ab	67 ab	63 bc	87 ab	88 ab	100 a	100 a
Permit + Loyant + COC + Urea	0 c	0 d	0 d	47 b	70 b	27 d	30 c	50 c	30 c	80 b	100 a	100 a
Urea *fb* Loyant + MSO	85 a	60 bc	63 bc	85 a	83 b	77 bc	63 ab	70 b	93 a	95 a	100 a	98 a
Urea *fb* Novixid + MSO	86 a	90 a	93 a	91 a	100 a	95 a	88 a	97 a	97 a	94 a	100 a	100 a
Urea *fb* Permit + Loyant + COC	50 b	55 bc	50 c	83 a	73 b	63 bc	83 a	60 bc	83 b	89 ab	100 a	97 a

† Treatment means within a column followed by different letters are different based on Tukey's honestly significant difference (α = 0.1).

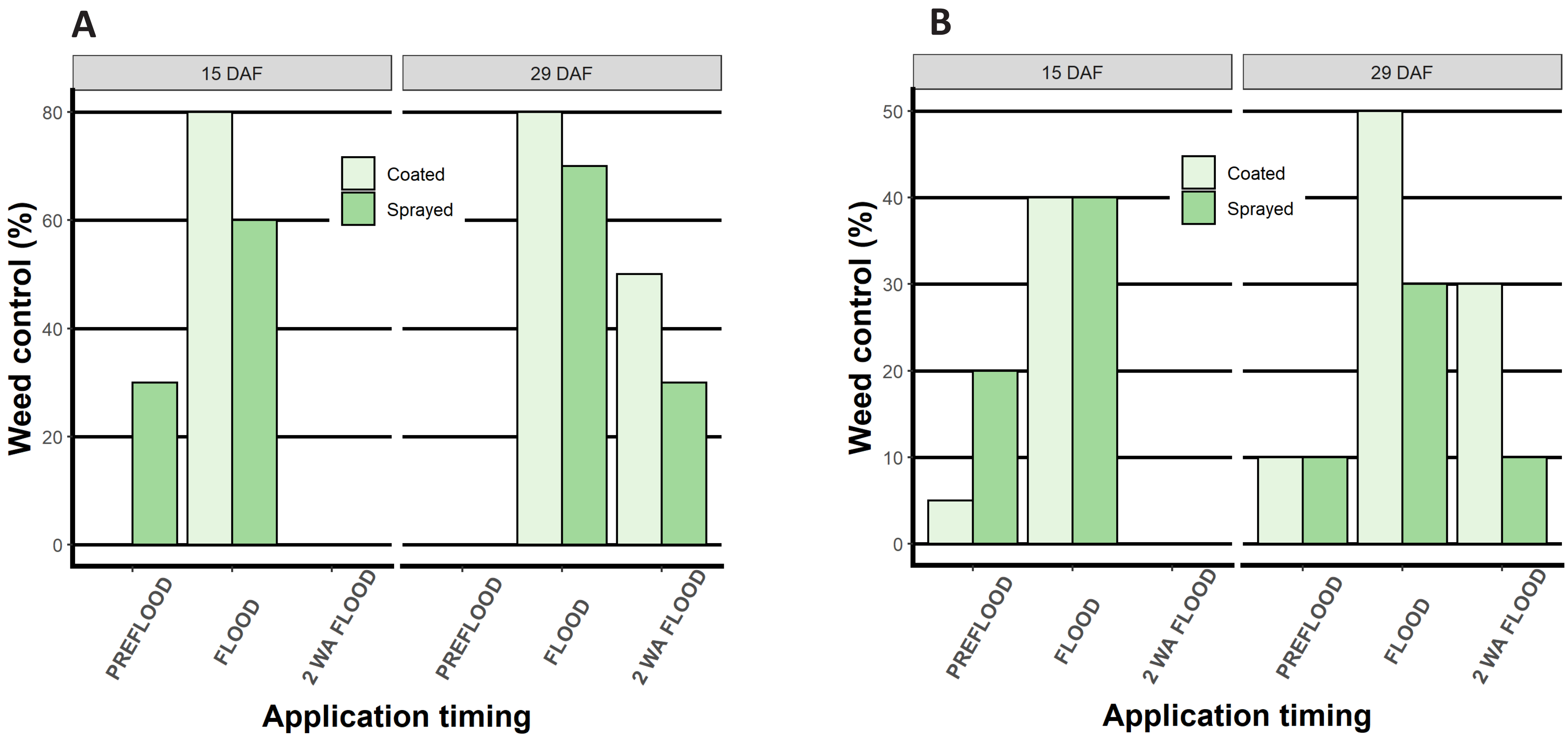

Fig. 1. Control of (A) sprangletop (*Diplachne* spp) and (B) hemp sesbania [*Sesbania herbacea* (Mill.) McVaugh] during field experiments conducted in 2022 at the University of Arkansas at Pine Bluff Small Farm Outreach Center near Lonoke, Ark., to evaluate the effect of coating urea with the 4-hydroxyphenylpyruvate dioxygenase-(HPPD-) inhibiting herbicide benzobicyclon (Rogue) for weed control. DAF = days after flood. WA = weeks after.

Use of a Fenclorim Seed Treatment to Safen Rice to a Delayed Preemergence Application of *S*-metolachlor on a Clay Soil

S.C. Noe,[1] J.K. Norsworthy,[1] T.H. Avent,[1] L.B. Piveta,[1] L.T. Barber,[2] and T.R. Butts[2]

Abstract

Barnyardgrass [*Echinochloa crus-galli* (L.) P. Beauv.] is a highly problematic weed in flooded rice (*Oryza sativa* L.) that can result in significant yield losses when left unchecked. New methods of barnyardgrass control will be needed to preserve high yields in Arkansas rice production. *S*-metolachlor is a chloroacetamide herbicide that provides residual control of grasses and small-seeded broadleaf weeds. An experiment was conducted in Keiser, Ark. to evaluate the efficacy of *S*-metolachlor in a rice system in conjunction with a fenclorim seed treatment to mitigate the risk of crop injury. Three rates of *S*-metolachlor (0.5, 1.0, and 1.5 lb ai/ac) were applied delayed-preemergence to 'Diamond' rice that was treated with fenclorim at 0 or 2.5 lb of ai/1000 lb-seed. Visual injury to rice and visual control of barnyardgrass were rated in comparison with the nontreated control and were evaluated throughout the season. Rough rice yield was evaluated after harvest. While visual rice injury was higher on average in the first two weeks after treatment without fenclorim, by 28 days after treatment (DAT) the low rate of *S*-metolachlor combined with a fenclorim seed treatment caused less than 17% injury. *S*-metolachlor provided effective visual control of barnyardgrass at all three rates up to 28 DAT that exceeded 90% control. Overall, the presence of fenclorim reduced injury to rice at each rate of *S*-metolachlor, while not having an impact on weed control. At a rate of 0.5 lb ai/ac of *S*-metolachlor with a fenclorim seed treatment, rice yield was comparable with the nontreated control. However, increasing rates of metolachlor reduced yield. If *S*-metolachlor becomes labeled for use in rice, this will provide an alternative site of action for weed control without requiring a herbicide resistance trait.

Introduction

Herbicide resistance is a major problem in terms of weed control in rice (*Oryza sativa* L.) production systems in the state of Arkansas. Barnyardgrass [*Echinochloa crus-galli* (L.) P. Beauv.] has evolved resistance to up to 5 unique sites of action and can result in substantial yield loss in rice of up to 70% when left unchecked (Smith 1968; Barber et al., 2022). Not only can barnyardgrass cause significant yield loss in rice, but when allowed to go to seed, barnyardgrass can produce up to 39,000 seeds per plant (Bagavathiannan et al., 2012). Previous research has explored the use of three HRAC/WSSA Group 15 chloroacetamide herbicides for residual control of grasses and small-seeded broadleaf weeds. However, these herbicides can potentially result in substantial injury to rice (Avent et al., 2023). One method of mitigating this injury to rice is the use of a safener to enhance metabolism of the herbicide in rice, and fenclorim has been shown to have this effect on rice sprayed with chloroacetamide herbicides (Hu et al., 2020). Fenclorim has previously been utilized as a herbicide safener when applied postemergence in a pre-mix that includes pretilachlor; however, this was primarily used in water-seeded rice in Asia (Quadranti and Ebner, 1983). While previous research has used acetochlor with a fenclorim seed treatment, *S*-metolachlor is another effective residual herbicide that can potentially be used with fenclorim in rice. The objective of this experiment was to determine the effectiveness of *S*-metolachlor in controlling barnyardgrass while minimizing rice injury with a fenclorim seed treatment.

Procedures

A field experiment was conducted in 2022 near Keiser, Arkansas at the University of Arkansas System Division of Agriculture's Northeast Arkansas Research and Extension Center to evaluate the efficacy of a capsule suspension formulation of *S*-metolachlor on a clay soil. The experiment was designed as a two-factor factorial within a randomized complete block design. The two factors evaluated were *S*-metolachlor rates (0.5, 1.0, and 1.5 lb of ai/ac) and the presence or absence of a fenclorim seed treatment at 2.5 lb of ai/1000 lb-seed. 'Diamond' rice was planted at 22 seeds/ft of row on 10 May and *S*-metolachlor was applied at a delayed preemergence application timing on 12 May with a CO_2-pressurized backpack sprayer calibrated to deliver 15 GPA at 3 mph with an AIXR 110015 nozzle. Visual barnyardgrass control was evaluated weekly until 28 days after treatment (DAT) relative to the nontreated control on a 0 to 100% scale, with 0% being no control and 100% being complete control. Visual rice injury was also evaluated weekly up to 35 DAT with 0% being no visible injury and 100% being plant mortality. At 28 DAT, postemergence herbicides were applied over the entire experiment to ensure rice

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yield estimates could be collected. Data were subjected to analysis of variance, and means were separated using Tukey's honestly significant difference with ($\alpha = 0.05$) using JMP Pro 17.0.

Results and Discussion

Traditionally, HRAC/WSSA Group 15 herbicides, including *S*-metolachlor, have resulted in varying rice injury levels dependent upon environmental conditions (Godwin et al., 2018). The interaction between *S*-metolachlor rate and seed treatment was significant for most of the visual injury ratings that took place up to 35 DAT (Table 1). By 28 DAT, rice treated with fenclorim and *S*-metolachlor at 0.5 lb ai/ac had recovered substantially showing only 18% injury (Table 1). Overall, at 28 DAT, fenclorim reduced rice injury at each *S*-metolachlor rate; however, both the 1.0 and 1.5 lb ai/ac rates resulted in greater than 48% injury regardless of seed treatment.

The interaction between herbicide rate and seed treatment was not significant in terms of weed control, meaning that the fenclorim seed treatment did not affect barnyardgrass control (Table 1). Visual rice injury was highly dependent on the rate of *S*-metolachlor, but in terms of visual barnyardgrass control, all three rates provided high levels of control up to 28 DAT (Table 1). The high rate of *S*-metolachlor did result in greater control when compared to both lower rates, but all three rates provided greater than 90% barnyardgrass control when averaged over seed treatment. While the exact length of effective residual barnyardgrass control is not clear from this trial, a high level of control was observed up to 28 DAT.

In terms of rough rice yield, the interaction between herbicide rate and seed treatment was significant, similar to the effect observed with visual rice injury (Table 1). At each rate of *S*-metolachlor, the presence of the fenclorim seed treatment resulted in greater rice yields (Table 1). At the lowest *S*-metolachlor rate with a fenclorim seed treatment, rice yield was comparable (241 bu./ac) to the nontreated control (227 bu./ac). Overall, as the rate of *S*-metolachlor increased, rice yield decreased when there was no seed treatment which was similar to previous results looking at the use of *S*-metolachlor in rice (Godwin et al., 2018).

Practical Applications

S-metolachlor is currently not available for use in U.S. rice production but has been shown to provide highly effective weed control in other cropping systems. The use of a fenclorim seed treatment in conjunction with *S*-metolachlor presents the opportunity for labeling this herbicide in rice which would add an additional site-of-action for controlling barnyardgrass and other highly problematic weeds in rice. If *S*-metolachlor becomes labeled for use in rice, a delayed-preemergence application timing of 0.5 lb ai/ac to provide an effective level of residual weed control of both grasses and small-seeded broadleaf weeds would be recommended.

Acknowledgments

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Table 1. Visual barnyardgrass control rated 14 and 28 days after treatment (DAT), visual rice injury evaluated 28 DAT, and rough rice yield collected at harvest.

		Barnyardgrass control[†]		Rice injury	
***S*-metolachlor**	**Fenclorim**	**14 DAT**	**28 DAT**	**28 DAT**	**Rice yield[‡]**
lb ai/ac	**lb ai/1000 lb**	------------------------------%	------------------------------		**bu./ac**
0		--	--	--	227
0.5		86 B[§]	91 B	48	216
1.0		96 A	91 B	69	167
1.5		100 A	99 A	82	141
	P-value[¶]	0.0116	0.0006	<0.0001	<0.0001
	0	94	92	88	214
	2.5	94	94	44	161
	P-value	0.9810	0.1846	<0.0001	<0.0001
***S*-metolachlor × fenclorim**					
0	0	--	--	--	220 AB
	2.5	--	--	--	234 A
0.5	0	86	90	79 AB	190 B
	2.5	85	92	17 D	241 A
1.0	0	96	90	90 AB	142 C
	2.5	97	92	48 C	193 B
1.5	0	100	98	96 A	95 D
	2.5	100	99	68 BC	189 B
	P-value	0.9649	0.7656	0.0319	0.0042

[†] Visual barnyardgrass control and rice injury were rated in comparison to the nontreated control.

[‡] Rough rice yields were recorded in bushels per acre.

[§] Means within a column for each factor level not containing the same letter differ according to Tukey's honestly significant difference (α = 0.05).

[¶] *P*-values were generated using analysis of variance in JMP version 17.0.

Harvest Weed Seed Control in Furrow-irrigated Rice Using Redekop™ Seed Control Unit

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Abstract

Barnyardgrass and Palmer amaranth are difficult-to-control weeds in furrow-irrigated rice (FIR), especially as herbicide resistance continues to grow throughout the mid-South. The lack of flood in FIR considerably changes weed management for rice. Most growers that use only chemical weed management programs are looking for alternative methods to limit soil weed seedbank replenishment from escaped weeds. The objective of this experiment was to evaluate the use of a Redekop™ Seed Control Unit (SCU) as a non-chemical management strategy for harvest weed seed control (HWSC) of barnyardgrass and Palmer amaranth in FIR. The experiment was designed as a randomized complete block (550 by 25 ft) with eight replications, in Keiser, Ark., in 2022. The two treatments evaluated were harvesting with the Redekop SCU engaged or harvesting with the Redekop SCU disengaged, as would occur in a conventional harvest rice field. In plots where the Redekop SCU was used, seedbank replenishment was reduced by 69% and 83% for barnyardgrass and Palmer amaranth, respectively. Based on initial evaluations, the Redekop SCU could be an asset for rice producers. As HWSC methods become available for commercialization, additional parameters need to be further evaluated, specifically shattering of weed seed before crop harvest and the height distribution of seed on targeted weed species. Incorporation of HWSC may allow producers searching for a systems approach to better manage difficult-to-control weeds by diminishing the number of viable seeds returned to the soil-seedbank.

Introduction

A survey of the rice growing regions in Arkansas reported that barnyardgrass [*Echinochloa crus-galli* (L.) P. Beauv.] and Palmer amaranth (*Amaranthus palmeri* S. Wats.) are the most problematic weeds in furrow-irrigated rice (FIR) (Butts et al., 2022). Rice growers in Arkansas rely heavily on herbicides for weed management (Barber et al., 2022). The many advantages of herbicides over other forms of weed control have resulted in almost exclusive reliance on herbicides to manage weeds in field cropping systems. However, the widespread evolution of resistance to herbicides in weed species (Heap, 2023) threatens herbicide sustainability and necessitates the development of new weed control tools.

Harvest weed seed control (HWSC) is a non-chemical control method that targets the mature weed plant to prevent its seed from entering the soil seedbank. Many weed species retain a large proportion of their seed during crop harvest, such as Palmer amaranth (Green et al., 2016; Schwartz-Lazaro et al., 2022) and barnyardgrass (Schwartz-Lazaro et al., 2021; Widderick et al., 2014). These weed seeds then enter the combine and evenly spread across the field to become a weed problem in subsequent years (Walsh et al., 2013).

One method of HWSC uses impact mills designed to destroy weed seeds in seed-bearing chaff material during crop harvest. In the past, the impact mill was attached to the combine as a trailer-mounted system incorporating a high-capacity cage mill to process chaff residue (Walsh et al., 2012). Currently, impact mills are integrated into the rear of the combine and use rotating and stationary bars to render weed seed non-viable upon exiting the system. Impact mills were first developed in Australia and have been highly adopted globally (Akhter et al., 2023; Walsh et al., 2018). The most used impact mills on the market are the Redekop™ Seed Control Unit (SCU), Seed Terminator™, WeedHOG®, and iHSD®. In a study including fifteen weed species with high relevance in the US soybean and rice production systems, the iHSD as a stationary unit was demonstrated to be highly effective in destroying 93% to 99% of weed seeds (Schwartz-Lazaro et al., 2017).

There needs to be more information on the effectiveness of impact mills used in rice production systems. This research aimed to evaluate the use of a Redekop SCU as a non-chemical management strategy for HWSC of barnyardgrass and Palmer amaranth in FIR.

Procedures

A field experiment was conducted in 2022 at the University of Arkansas System Division of Agriculture's Northeast Research and Extension Center, Keiser, Arkansas. A hybrid cultivar (RT XP753) was drill-seeded at 11 seeds per foot on 5 May 2022. The experiment was organized in a single-factor randomized complete block with eight replications. The plot dimensions were 550 ft long by 25 ft wide with furrow irrigation. The weed management relied on herbicides with no or short residual to allow some weed plants to be present at harvest (Table 1). The harvest aid applica-

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tion was made by airplane. All other applications were made at 6 miles per hour with a John Deere 6000 sprayer using AIXR11004 nozzles calibrated to deliver 15 gal/ac.

Each 0.3 ac plot was harvested on 19 September 2022, using a John Deere S690 combine equipped with a 25-foot draper head and an on-combine Redekop SCU. The two treatments evaluated were harvesting with the Redekop SCU engaged or harvesting with the Redekop disengaged, as would occur in a conventionally harvested rice field. The combine was operated under the same harvest settings and speed, approximately 2 mph, for both treatments.

To measure header and threshing loss of weed seed, two sets of two metal trays, each measuring 78 in long by 20 in wide by 1 in deep (10.7 square feet), were placed in the field 50 ft apart to avoid contamination. For header loss collection, the combine was operated at full capacity and harvest speed until the header passed over the collection trays. Once the header passed through the set of trays, the combine was stopped to prevent contamination of residues that were exiting the rear of the combine. For threshing loss, the set of two metal trays previously placed in the field was collected. All residue in the trays was emptied into a paper bag and stored for subsequent processing to determine the number of viable weed seeds.

All samples were sifted through a series of sieves to separate larger pieces of chaff, straw, and debris from the weed seeds. After being sieved, each sample was mixed with growing medium (Pro-Mix LP15) and placed in 1020 greenhouse flats. The flats containing the samples were maintained in the greenhouse at 80 °F with natural light supplemented with lamps providing a 14-h photoperiod and were watered as needed. The exhaustive germination of Palmer amaranth and barnyardgrass was determined in each flat for 12 weeks following planting.

Data were subjected to an analysis of variance in JMP Pro v. 16 (SAS Institute Inc., Cary, N.C.) and means were separated using Fisher's protected least significant difference with an alpha value of 0.05.

Results and Discussion

This research defines header loss as weed seed lost at the combine head due to shattering. Regardless of the harvest method, if the weed seed is lost in the head, the seed will enter the soil seedbank and persist for subsequent growing seasons. The threshing loss was defined as any weed seed that exited the combine's rear through the straw spreader and/or Redekop SCU back to the soil surface. There was no significant difference in header loss regardless of harvest method or weed species, ranging from 5 to 8% for Palmer amaranth and barnyardgrass, respectively. The results for header loss suggest that more than 95% of weed seeds present at harvest time go through the combine. The weed seed that enters the combine could be exported from the field within the rice grains or exiting the combine by straw and/or chaff residue that return to the soil seedbank.

The Redekop SCU was found to be effective in destroying Palmer amaranth (Fig. 1) and barnyardgrass seeds (Fig. 2). When the Redekop SCU was engaged the viable Palmer amaranth and barnyardgrass seeds per square foot were 1.1 and 2.1, respectively. However, when the Redekop SCU was disengaged, the viable Palmer amaranth and barnyardgrass seeds per square foot were 6.6 and 6.7, respectively. Furthermore, when Redekop SCU was engaged, seedbank replenishment was reduced by 83% and 69% for Palmer amaranth and barnyardgrass, respectively. Green et al. (2020) concluded that 85% of Palmer amaranth seeds exited the combine through the chaff fraction where the Redekop SCU is effective. In other words, the effectiveness of Redekop SCU destroying weed seeds is higher than 83% for Palmer amaranth because a portion of the weed seeds did not reach the impact mill and exited the combine by the straw fraction.

Practical Applications

Based on initial evaluations, the Redekop SCU could be an asset for rice producers. As HWSC methods become available for commercialization, additional parameters need to be further evaluated, specifically shattering of weed seed before crop harvest and the height distribution of seed on targeted weed species. Incorporation of HWSC may allow producers searching for a systems approach to better manage difficult-to-control weeds by diminishing the number of viable seeds returned to the soil-seedbank.

Acknowledgments

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Table 1. Weed management program for furrow-irrigated rice in Keiser, Ark., 2022.

Herbicide	Timing	Rate
Obey™ (clomazone + quinclorac)	PRE (at planting)	45.6 fl. oz/ac
Stam® (propanil)	EPOST (4 WAP)	4 qt/ac
Bolero® (thiobencarb)		8 qt/ac
Loyant® (florpyrauxifen-benzyl)	POST (7 WAP)	8 fl oz/ac
Permit® (halosulfuron)		1 oz/ac
MSO[a]		0.5 % v/v
Defol® 5 (sodium chlorate)	Harvest aid (10 DBH)	4 qt/ac

[a] Abbreviations: WAP = weeks after planting; DBH = days before harvest; PRE = preemergence; EPOST = Early postemergence; POST= Postemergence; MSO = methylated seed oil.

Fig. 1. Viable Palmer amaranth seeds (sq ft) exiting the combine. Treatments with the same letter are not significantly different according to Fisher's protected least significant difference at α = 0.05.

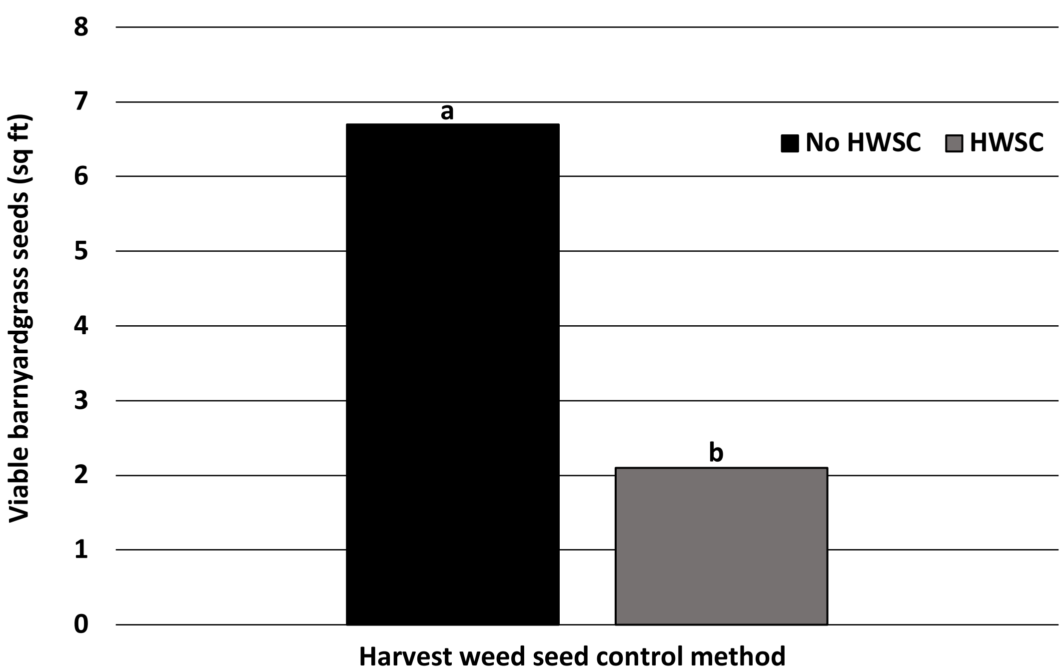

Fig. 2. Viable barnyardgrass seeds (sq ft) exiting the combine. Treatments with the same letter are not significantly different according to Fisher's protected least significant difference at α = 0.05.

Utilizing Benzobicyclon to Control Weedy Rice in Imidazoline-Resistant Rice Systems

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Abstract

An increase in weedy rice (*Oryza sativa* L.) populations resistant to herbicides has heightened the need for alternative modes of action. Benzobicyclon is a 4-hydroxyphenylpyruvate dioxygenase inhibitor, the first of its kind labeled in rice. Benzobicyclon has shown substantial control of various monocot and broadleaf species, and this study evaluated the effectiveness of benzobicyclon as a weed control partner in imidazoline-resistant rice weed control systems. The study was organized as a split-plot in a randomized complete block design. The whole-plot factor was the presence or absence of benzobicyclon at 12.6 fl oz/ac applied post-flood, and the subplot factor was herbicide treatments containing imazamox and imazethapyr applied at either 2- to 3-leaf (early postemergence) or 5-to 6-leaf (preflood). Weedy rice and barnyardgrass (*Echinochloa crus-galli*) visual control, visual rice injury, and stunting evaluations were taken five times up to six weeks after post-flood treatment (WAFT). Rough rice yield was taken at crop maturity. Visual injury was minimal, never exceeding 12%, and there was no more than 8% injury due to bleaching. Improved visual weedy rice control was observed with the addition of benzobicyclon to 1) no additional herbicide, 2) imazamox at 5 fl oz/ac applied at 5- to 6-leaf rice, and 3) imazamox at 5 fl oz/ac applied post-flood. Rice yields were similar among all treatments. The findings from this research show that adding benzobicyclon to existing weed control programs in imidazoline-resistant rice can improve weedy rice control and aid in lowering weedy rice seedbank density.

Introduction

Benzobicyclon is a Herbicide Resistance Action Committee and Weed Science Society of America group 27 herbicide that inhibits 4-hydroxyphenylpyruvate dioxygenase (USEPA, 2021) and is the first of its kind labeled in rice (*Oryza Sativa* L.). In Arkansas, benzobicyclon has been used in dry- and water-seeded rice to control aquatics, broadleaves, sedges, and grasses. Previous research conducted by the University of Arkansas System Division of Agriculture evaluated the effectiveness of benzobicyclon added to quizalofop- and imidazoline-resistant rice (Patterson et al., 2022). In addition, previous research was conducted to determine the control of different weedy rice (*Oryza sativa* L.) accessions from three rice-producing states when utilizing benzobicyclon. It was found that the sensitivity of weedy rice varies across accessions; however, it could provide additional control of weedy rice (Young et al., 2018). The objective of this study was to evaluate the effectiveness of benzobicyclon as a weed control partner in imidazoline-resistant rice weed control systems. The integration of benzobicyclon alongside imidazoline-resistant rice weed control programs would provide an additional site of action for producers and allow for potentially improved control of a broadened range of weeds. Furthermore, the addition of benzobicyclon could provide producers with an opportunity to control weedy rice populations.

Procedures

A field study was conducted at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center, near Stuttgart, Arkansas, in 2022 to evaluate the effectiveness of benzobicyclon as a weed control partner in imidazoline-resistant rice weed control systems. FullPage® rice (variety RT7321) was drill-seeded into 6 ft by 17 ft plots at 11 seeds/row ft and maintained as conventional-paddy rice. Clomazone at 0.3 lb/ac was applied to the entire test site immediately after drill-seeding FullPage® rice. The study was organized as a split-plot in a randomized complete block design with four replications. The whole-plot factor was with or without benzobicyclon at 0.22 lb/ac applied post-flood. The subplot factor was herbicide treatments that included 1) no additional herbicide, 2) imazethapyr at 0.25 lb/ac applied early postemergence (2- to 3-leaf rice) followed by (fb) imazamox at 0.04 lb/ac applied pre-flood (5- to 6-leaf rice), 3) imazethapyr at 0.25 lb/ac applied early postemergence fb imazamox 0.04 lb/ac applied post-flood, 4) imazamox at 0.04 lb/ac applied pre-flood, and 5) imazamox at 0.04 lb/ac applied post-flood. Weedy rice and barnyardgrass [*Echinochloa crus-galli* (L.) P. Beauv.] visual control along with visual rice injury were collected. Evaluations were taken 4 weeks after the post-flood treatment (WAFT). Rough rice yield was collected at crop maturity. All data from this experiment were analyzed using JMP Pro V. 17 and subjected to a restricted maximum likelihood estimation of variance components with means separated using Tukey's honestly significant difference ($\alpha = 0.05$).

Results and Discussion

Rice displayed minimal visual injury across treatments at all evaluation timings, reaching no more than 12% injury. Most injury in benzobicyclon-treated plots resulted from slight bleaching,

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which never exceeded 8% for any specific treatment. Treatments without benzobicyclon showed the least amount of injury, with an average of under 1%, compared to an average of 6% whenever benzobicyclon was included (Fig. 1). The addition of benzobicyclon to each herbicide program improved visual weedy rice control in the following treatments: 1) no additional herbicide, 2) imazamox 0.04 lb/ac applied pre-flood, and 3) imazamox at 0.04 lb/ac applied post-flood. At 4 WAFT, all benzobicyclon-containing herbicide programs had superior weedy rice control compared to the corresponding treatments without benzobicyclon (Fig. 2). A study evaluating weedy rice control utilizing benzobicyclon in quizalofop- and imidazoline-resistant rice systems found that full-season treatments that included benzobicyclon provided comparable or improved weed control to that of the non-benzobicyclon treatments (Patterson et al., 2022). Excluding the nontreated control, rice in all treatments produced similar yields, which were at least 54 bu./ac greater than the nontreated control (data not shown). There was no attempt to differentiate weedy rice grain from the cultivated grain or associated dockage that could result from grain contamination.

Practical Applications

The addition of benzobicyclon to imidazolinone weed control programs was beneficial for weedy control. Use of benzobicyclon resulted in low levels of rice injury. The addition of benzobicyclon to weed control programs in imidazolone-resistant rice will likely improve weedy rice control, consequently lowering weedy rice seedbank density in subsequent years.

Acknowledgments

We thank Gowan Company LLC for providing benzobicyclon and financial support. We also thank the University of Arkansas System Division of Agriculture's Rice Research and Extension Center and the Arkansas Rice Research and Promotion Board for their support.

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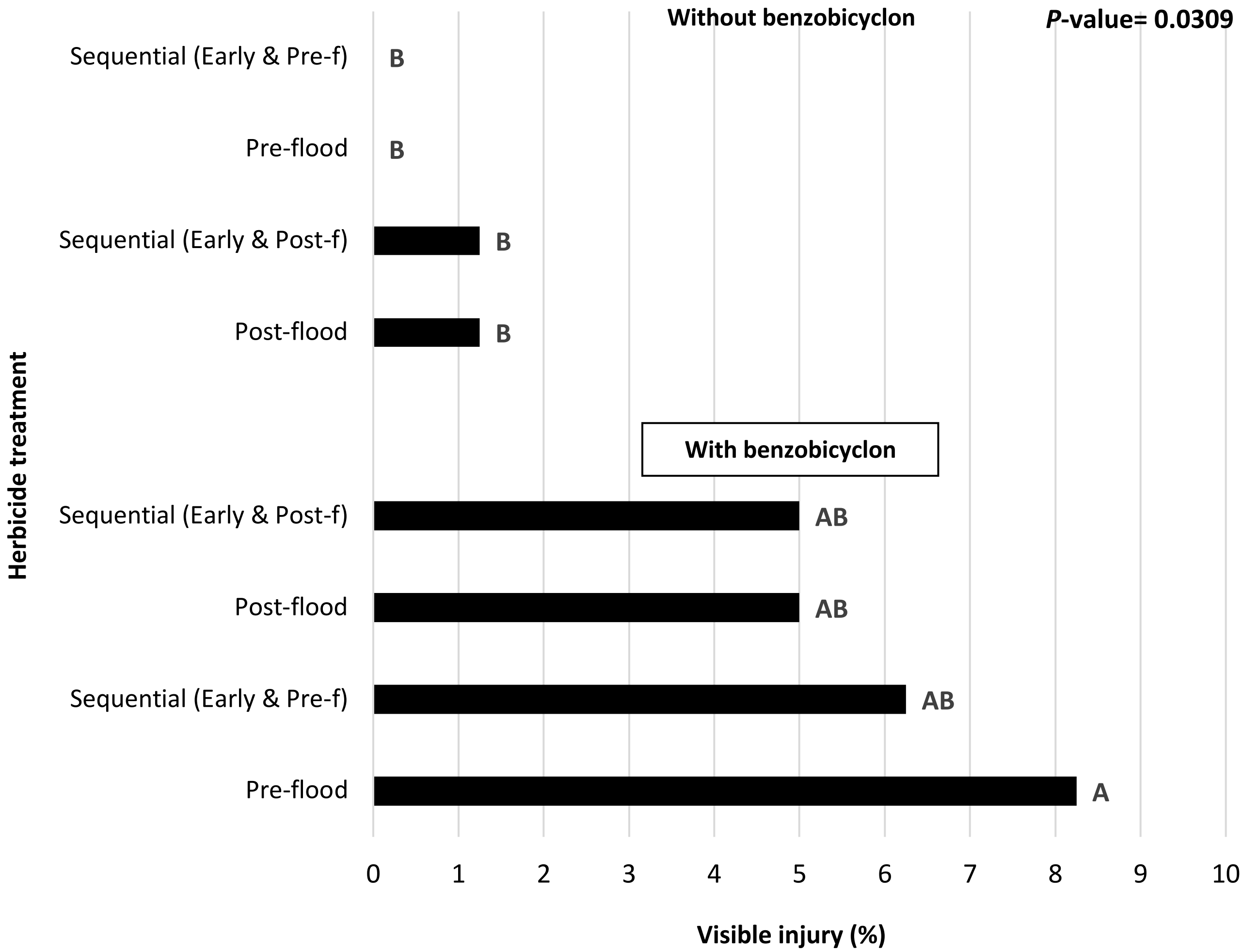

Fig. 1. Rice injury at 4 weeks after post-flood treatment (WAFT), Stuttgart, Arkansas. Means followed by the same letter are not different (α = 0.05). "Post-f' stands for post-flood treatments; "Pre-f" starts for pre-flood treatments; "Early" stands for early postemergence treatments; "Sequential" denotes treatments that were applied one after the other.

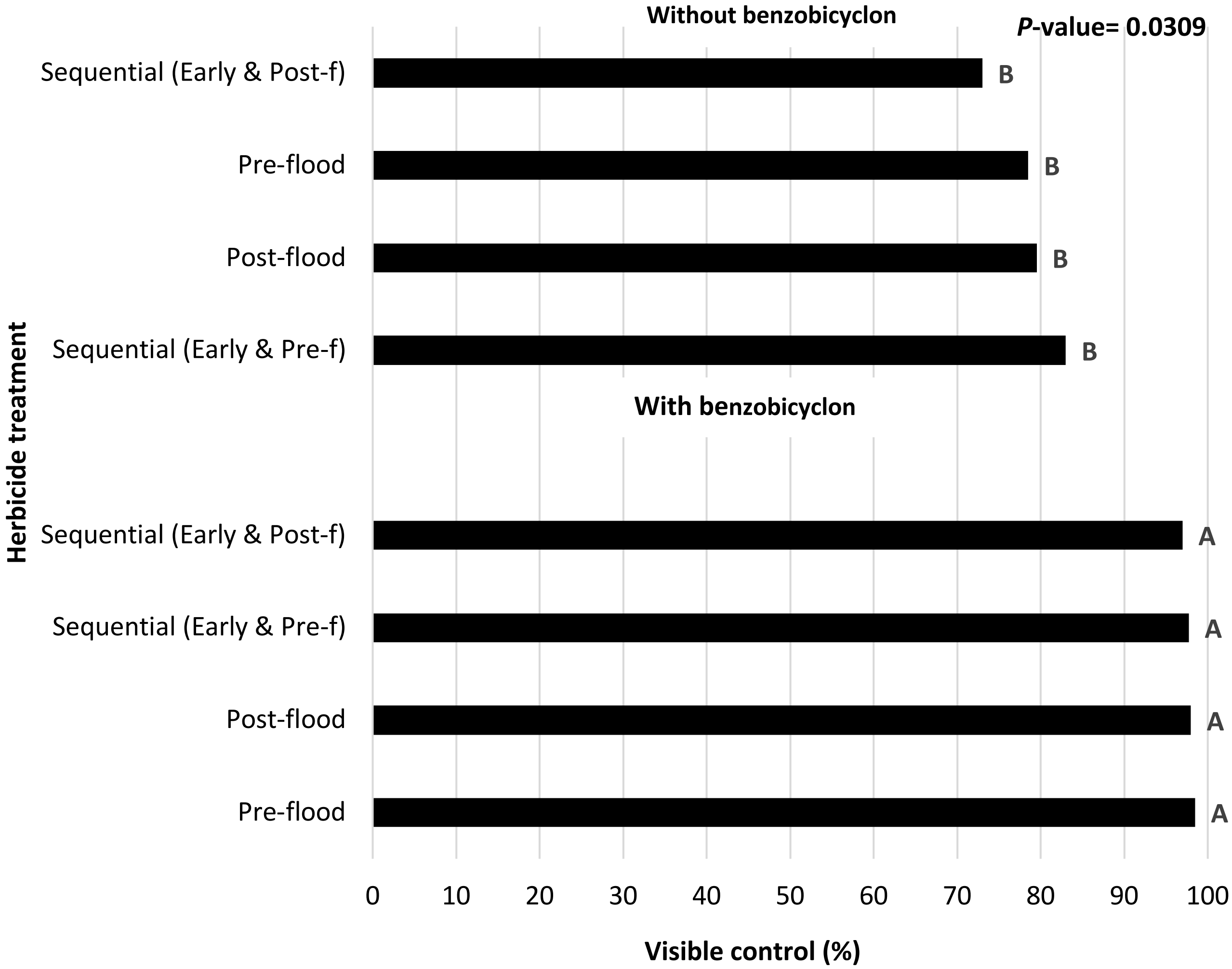

Fig. 2. Weedy rice visual control at 4 weeks after the post-flood treatment (WAFT), Stuttgart, Arkansas. Means followed by the same letter are not different (α = 0.05). "Post-f' stands for post-flood treatments; "Pre-f" starts for pre-flood treatments; "Early" stands for early postemergence treatments; "Sequential" denotes treatments that were applied one after the other.

Cultural Weed Management Strategies in Flooded Rice: Effects of Rice Cultivar and Drill Row Width on Barnyardgrass [*Echinochloa crus-galli* (L.) P. Beauv.]

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Abstract

In a flooded Arkansas rice system, producers and consultants identified the most problematic weed they face is barnyardgrass [*Echinochloa crus-galli* (L.) P. Beauv.]. Due to the evolution of herbicide resistance and the overall hardiness of the weed, other control measures are needed for barnyardgrass in rice. The objective of this study was to evaluate the influence of rice cultivars and the manipulation of drill row width for barnyardgrass control in rice. Field experiments were conducted at the University of Arkansas System Division of Agriculture's Pine Bluff Small Farm Outreach Center, near Lonoke, Arkansas, Pine Tree Research Station, near Colt, Arkansas, and the Rohwer Research Station, near Watson, Arkansas in 2021 and 2022. The experiments were designed as randomized complete block split-plot designs (16 treatments) replicated 4 times with 4 nontreated controls for each drill width spacing. Each trial consisted of a whole plot factor of 4 drill row width spacings: 5, 7.5, 10, and 15 in. The subplot factor consisted of 4 cultivars: medium-grain inbred (CLM04), long-grain inbred (CLL16), long-grain hybrid (RT 7301), and FullPage long-grain hybrid (RT 7521 FP). Results indicated no interaction of drill row width spacing and rice cultivar for any response variables. A decrease in barnyardgrass density was observed for the 7.5-in. spacing compared to the 15-in. spacing across site-years for the 5- to 6-leaf (preflood) and preharvest rice stages. A 43% decrease in barnyardgrass density was observed for the hybrid cultivars compared to the inbred at the preharvest timing. Based on small unmanned aerial system (sUAS) imagery at panicle differentiation, there was a 20 percentage point decrease in canopy coverage from the 7.5 in. drill row width to the 15 in. width. This research provides insights on alternative weed management efforts through more precise drill row width spacing and cultivar selection in an Arkansas flooded rice system.

Introduction

An online survey conducted in the fall of 2020 highlighted that barnyardgrass [*Echinochloa crus-galli* (L.) P. Beauv.] was the most problematic weed in Arkansas flooded and furrow-irrigated rice production systems (Butts et al., 2022). Barnyardgrass has become the dominant pest in Arkansas rice primarily due to the rapid evolution of herbicide resistance to many different modes of action (Talbert and Burgos, 2017). Liebman and others found that the use of "many little hammers" (combined weed control methods) has more advantages than just using "one large hammer" (chemical control) to control problematic weeds and thus increased efforts are needed to use more integrated weed management strategies (Liebman et al., 1997). The objective of this study was to evaluate the influence of rice cultivars and the manipulation of drill row width for barnyardgrass control in rice.

Procedures

Field experiments were conducted at the University of Arkansas System Division of Agricuilture's Pine Bluff Small Farm Outreach Center near Lonoke, Arkansas, Pine Tree Research Station near Colt, Arkansas, and the Rohwer Research Station near Watson, Arkansas in 2021 and 2022. The experiments were designed as randomized complete block split-plot designs (16 treatments) replicated 4 times with 4 nontreated controls for each drill width spacing. Each trial consisted of a whole plot factor of 4 drill row width spacings: 5, 7.5, 10, and 15 in. The subplot factor consisted of 4 cultivars: medium-grain inbred (CLM04), long-grain inbred (CLL16), long-grain hybrid (RT 7301), and FullPage long-grain hybrid (RT 7521 FP). The inbred cultivars were planted at 36 seed/ft^2 and the hybrid cultivars at 12 seed/ft^2. A non-commercial herbicide program was applied to better assess the cultural weed control factors listed above. Applications were made by a CO_2-pressurized sprayer with a tractor-mounted sprayer calibrated to apply 10 GPA at 4 mph. At the preemergence application timing, clomazone (Command) at 0.28 lb ai/ac (12.8 fl oz/ac) and saflufenacil (Sharpen) at 0.06 lb ai/ac (3 fl oz/ac) were sprayed using an AI110015 nozzle. At the postemergence application timing, bentazon (Basagran) was applied at 0.5 lb ai/ac (1 pt/ac) for rice flatsedge (*Cyperus iria*) control. Barnyardgrass density assessment (2-2.7 ft^2 quadrants) was assessed at the 5- to 6-leaf rice stage (preflood) and preharvest rice stage of the experiment. Small unmanned aerial system (sUAS)

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Results and Discussion

During the experiments, no interaction was observed between drill row width spacing and rice cultivars for any response variables. Across all site-years, a drill row width effect could be seen at the preflood stage for barnyardgrass density count. A 60% decrease in barnyardgrass density was observed in the standard 7.5-in. spacing compared to the 15-in. spacing (Fig. 1). Barnyardgrass density in the 5-in. spacing was similar to the 7.5-in., and the 10-in. spacing was comparable to the 15-in. spacing, which generally shows that as the row width spacing narrows, weed density decreased. At the preharvest rice stage across site-years, the main effects for both drill row width and cultivar were observed. A 56% decrease in barnyardgrass panicle density was observed for the 7.5-in. spacing compared to the 15-in. spacing (Fig. 2). This comparison was similar to what was observed at the preflood rice stage showing that the narrower spacing reduced weed density throughout the season. The hybrid cultivars provided a 43% decrease in panicle density at the preflood stage compared to the inbred cultivars (Fig. 2). Based on the sUAS imagery at panicle differentiation, there was a 20 percentage point decrease of canopy coverage from the 7.5-in. drill row width to the 15-in. (Fig. 3). No canopy coverage differences were observed at the preflood rice stage for both drill row width and cultivar.

Practical Applications

The drill row width spacings showed a similar trend throughout the rice growing season that a narrower spacing reduced barnyardgrass density compared to wider spacings. The standard 7.5-in. spacing is still demonstrated to be the most optimal width for weed control in rice. If 15-in. precision planters would become widely available, then additional research would be needed for the following: 1) a different weed control program to better fit the wider drill row width would be required to reduce the soil weed seedbank, and 2) to evaluate the economics of weed control cost and seeding rates to maximize profitability. The hybrid cultivars could possess the ability to provide added weed control over conventional cultivars because of the prolific growth characteristics they have. To better maximize weed control with these alternative cultural control measures, faster canopy coverage is needed to prevent weed escapes in production fields. The most optimized way to do this was to plant in a narrower drill row width and use of hybrid cultivars.

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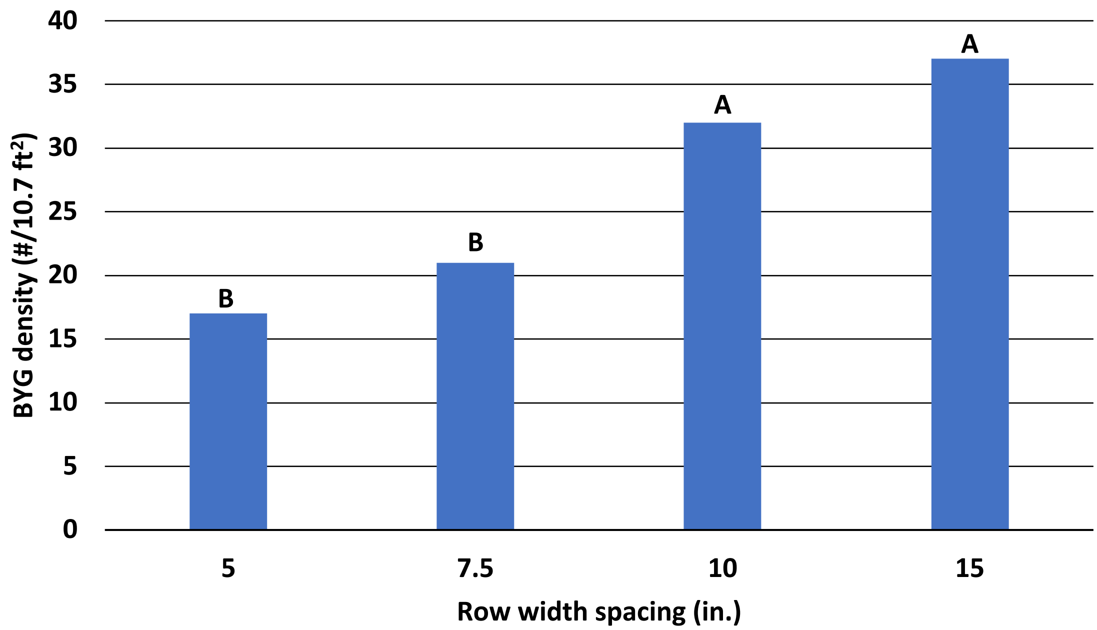

Fig. 1. Barnyardgrass density for each drill row width spacing at the preflood rice stage across all site-years. Treatments with the same letter are not different according to Tukey's honestly significant difference test at α = 0.05.

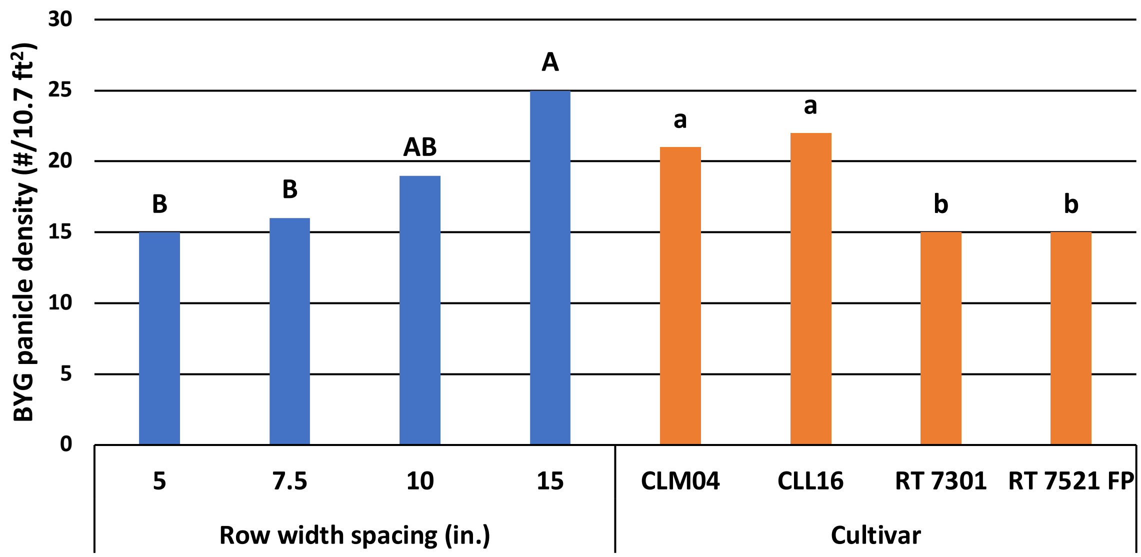

Fig. 2. Barnyardgrass panicle density for each drill row width spacing and cultivar at the preharvest rice stage across all site-years. Treatments with the same letter within fixed effect are not different according to Tukey's honestly significant difference test at α = 0.05.

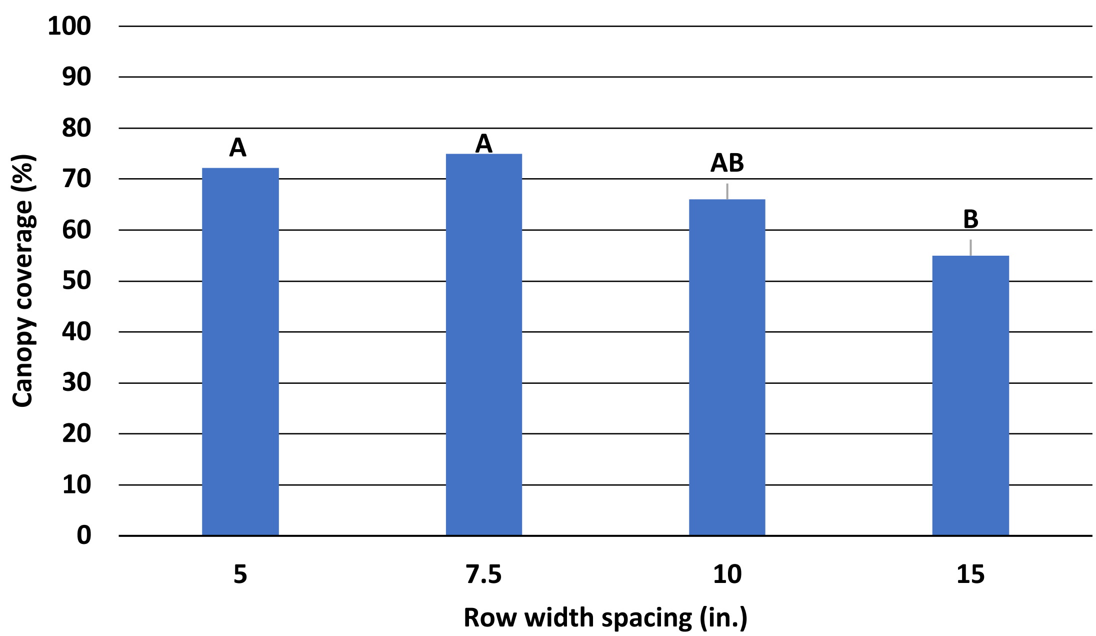

Fig. 3. Canopy coverage (%) for each drill row width spacing at the panicle differentiation rice stage across locations for the 2022 year. Treatments with the same letter are not different according to Tukey's honestly significant difference test at α = 0.05.

Comparison of Max-AceTM versus Provisia™ Programs

D.A. Smith,[1] J.K. Norsworthy,[1] L.B. Piveta,[1] T.H. Avent,[1] L.T. Barber,[2] and T.R. Butts[2]

Abstract

Provisia™ and Max-Ace™ rice, *Oryza sativa* L., are two options available to producers that enable the use of quizalofop for barnyardgrass and weedy rice control among other grass weeds. The Highcard™ formulation of quizalofop is labeled for use on Max-Ace™ rice while the Provisia™ formulated product is labeled for use on Provisia™ rice. Provisia™ and Highcard™ formulations differ in that the latter also contains isoxadifen to help safen the herbicide in Max-Ace™ rice. Weed control and crop tolerance were evaluated at the Rice Research and Extension Center near Stuttgart, Arkansas to compare Highcard™-based herbicide programs in Max-Ace™ rice to a standard Provisia™ program in Provisia™ rice. For both technologies, long-grain, inbred cultivars were drill-seeded at recommended densities. Both rice technologies included sequential applications of Provisia™ or Highcard™ with Zurax™ in the first postemergence application and Vopak™ in the second application (preflood). Two additional programs in Max-Ace™ rice included the addition of Zurax™ and Permit Plus™ or Vopak™ and Stam™ at early postemergence and preflood applications, respectively. Provisia™ rice was injured 17% by Provisia™ herbicide at 3 weeks after final treatment (WAFT), whereas rice injury in the Highcard™ programs ranged from 1% to 6% at the same evaluation. Weedy rice, *Oryza sativa* L., control was greater than 95% in all treatments at 4 WAFT. Barnyardgrass, *Echinochloa crus-galli* (P.) Beauv., control exceeded 99% at 4 WAFT for all herbicide treatments. Rough rice yields were similar among all herbicide treatments, regardless of rice technology. These findings show that timely applications of Highcard™ in Max-Ace™ rice result in end-of-season weedy rice and barnyardgrass control levels comparable to those in a Provisia™ rice system.

Introduction

The development of weed resistance to herbicides in rice production continues to be a problem for producers. The use of herbicide-tolerant rice varieties allows more options for producers to control herbicide-resistant weeds. The potential for gene-flow between hybrid and weedy rice has been observed after continued use of herbicide-tolerant rice hybrids (Wedger et al., 2022). Provisia™ and Max-Ace™ rice varieties, both herbicide-tolerant to quizalofop-P-ethyl, were recently released into commercial production in 2018 and 2021, respectively. Quizalofop is a WSSA group 1 herbicide that inhibits the acetyl CoA carboxylase enzyme used to control grasses (WSSA, 2023). Provisia™ rice is tolerant due to a mutation where a leucine amino acid residue is substituted for an isoleucine amino acid at position 1792 in the ACCase amino acid sequence (Famoso and Linsombe, 2020). While Max-Ace™ is tolerant due to a mutation substituting a serine amino acid for a glycine amino acid at position 2096 in the ACCase amino acid sequence (Hinga et al., 2013). This allows producers two options to aid in the control of herbicide-resistant weeds.

Highcard™ is a formulation of quizalofop-P-ethyl that contains a safener, isoxadifen, for the use on Max-Ace™ rice (Shen et al., 2017). The Provisia™ herbicide formulation of quizalofop-P-ethyl, for use on Provisia™ rice, does not have a safener. The difference in herbicide formulations and genetic sites of crop tolerance in these systems prompted the need for this study to evaluate crop tolerance and weed control in each system.

Procedures

A field experiment was conducted in 2021 at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center near Stuttgart, Arkansas. A Max-Ace™ variety and Provisia™ variety were drill-seeded at 12 seeds/ft, and plot dimensions were 6 ft wide by 17 ft long. The experiment was arranged as a randomized complete block design with four replications. The trial was irrigated using standard flooded rice methods in Arkansas. The whole-plot factor was herbicide programs: 1) no herbicide, 2) Provisia™ and quinclorac sprayed early postemergence, 1- to 2-leaf rice (EP) and Provisia™ and clomazone at preflood, 4- to 5- leaf (PREF), 3) Highcard™ and quinclorac (EP) and Highcard™ and clomazone (PREF), 5) Highcard™ and quinclorac (EP) and Highcard™ and halosulfuron plus thifensulfuron (PREF), 6) Highcard™ and clomazone (EP) and Highcard™ and propanil (PREF). Highcard™ treatments were applied to Max-Ace™ rice while Provisia™ treatment was applied to Provisia™ rice. Herbicides were applied at the following rates: Provisia™ and Highcard™, both quizalofop-P-ethyl, at 0.107 lb ai/ac, Zurax™, quinclorac, at 0.375 lb ai/ac, Vopak™ 3ME, clomazone, at 0.187 lb ai/ac, Permit Plus™, halosulfuron and

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thifensulfuron, at 0.035 lb ai/ac, and Stam™, propanil, at 3.0 lb ai/ac. A blanket preemergence application of Vopak™ 3ME at 0.30 lb ai/ac and Sharpen™ at 0.04 lb ai/ac were applied to all treatments except the no herbicide plots. All postemergence treatments included crop oil concentrate at 1% v/v. All applications were made at 3 miles per hour with a CO_2-pressurized backpack sprayer using AIXR110015 nozzles calibrated to deliver 15 gal/ac. Crop injury, weedy rice, and barnyardgrass, control were rated 3 weeks after EP treatments and 2, 3, and 4 weeks after PREF treatments. Rough rice yield data were obtained at the end of the season. Data were subjected to an analysis of variance in JMP Pro v. 17 (SAS Institute Inc., Cary, N.C.).

Results and Discussion

Crop injury was observed but not statistically significant. Provisia™ rice was injured 17% by Provisia™ herbicide at 3 weeks after final treatment (WAFT), whereas rice injury in the Highcard™ programs ranged from 1 to 6% at the same evaluation (data not shown).

Weed control was not significantly different between Provisia and Highcard programs. All herbicide treatments resulted in greater than 90% control of weedy rice following the early postemergence application and greater than 95% control of weedy rice by 4 WAFT (data not shown). All herbicide applications resulted in greater than 99% control of barnyardgrass 4 WAFT. This indicates equivalent weed control when using either the Provisia™ rice program or Max-Ace™ rice program. This is a high level of control but still not 100%. This will add the potential for gene-flow from Provisia™ or Max-Ace™ rice to weedy rice.

Rough rice yield varied from 133 to 162 bu./ac across herbicide treatments (Fig. 1) but was not significantly different. This indicates that the low levels of observed injury did not impact yield of either Provisia™ rice compared to Max-Ace™ rice.

Practical Applications

The Max-Ace™ rice program is comparable in control and crop safety to the Provisia™ rice program. Although all herbicide treatments had high levels of weedy rice and barnyardgrass control, there were still escapes. These escapes could become issues unless crop rotation is implemented so that glyphosate, glufosinate, or other herbicides can be used to eliminate the potential development of herbicide resistance to quizalofop to maintain the efficacy of these programs.

Acknowledgments

The authors would like to thank the University of Arkansas System Division of Agriculture, the Rice Research and Extension Center in Stuttgart, Arkansas, and the Arkansas Rice Checkoff Program, and Adama for providing funding for this research administered by the Arkansas Rice Research and Promotion Board.

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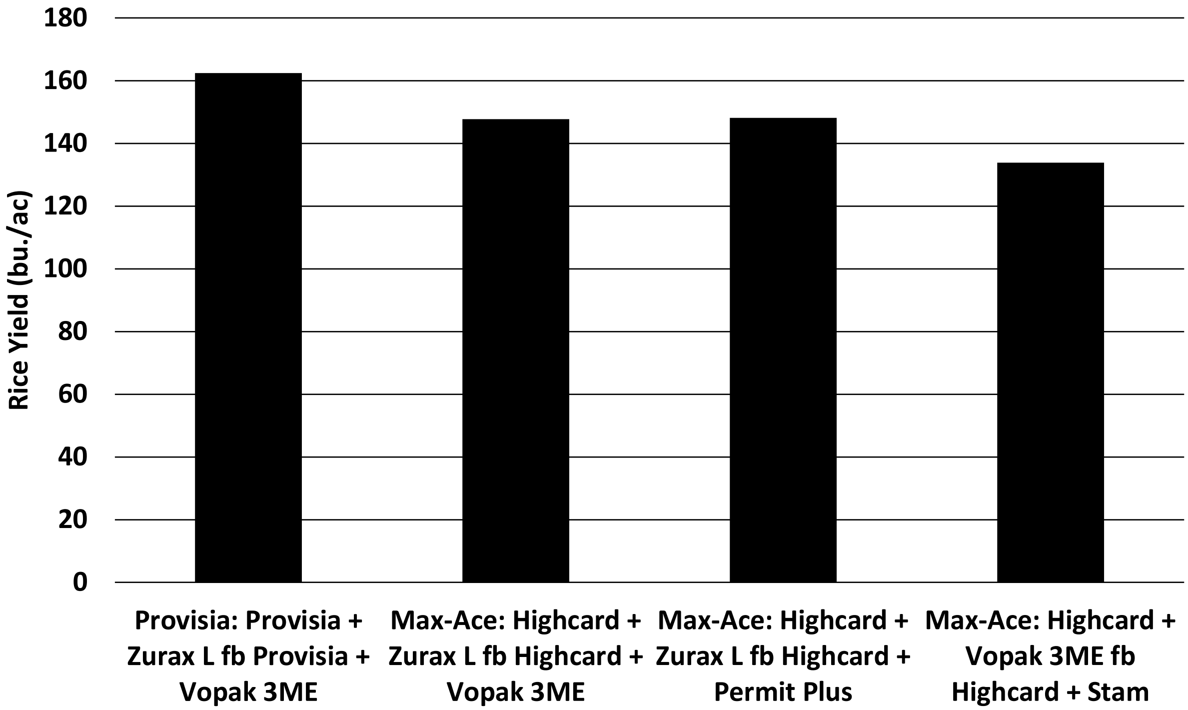

Fig. 1. Rice yield (bu./ac) following quizalofop herbicide treatments applied early postemergence followed by (fb) preflood applications on Provisia or Max-Ace rice. Application timings were early postemergence followed by (fb) preflood. No significant differences were found.

Optimization of a Clomazone: Oxyfluorfen Mixture for Extended Barnyardgrass Control on a Silt Loam Soil

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Abstract

The ROXY® Rice Production System (RRPS) was recently commercialized in California, allowing producers to apply oxyfluorfen (HRAC/WSSA Group 14) both preemergence and postemergence. The use of oxyfluorfen in the RRPS provides producers with an additional herbicide option for barnyardgrass [*Echinochloa crus-galli* (L.) P. Beauv.] control in rice (*Oryza sativa* L.). A field experiment was conducted at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center near Stuttgart, Ark., in 2022, to evaluate residual barnyardgrass control with clomazone and oxyfluorfen alone and in mixture. Herbicide treatments included clomazone at 0.25 or 0.3 lb ai/ac, and oxyfluorfen at 0.6 or 0.75 lb ai/ac applied preemergence followed by a sequential postemergence application. A 1:2 and 1:3 ratio of clomazone and oxyfluorfen (0.3 + 0.6 lb ai/ac and 0.25 + 0.75 lb ai/ac) were also evaluated. At 3 weeks after the preemergence application, but prior to the postemergence application, all rates of oxyfluorfen and clomazone alone provided ≥94% visual control of barnyardgrass. All combinations of clomazone and oxyfluorfen, provided 100% barnyardgrass visual control at 3 weeks after the preemergence application. At 5 weeks after the postemergence application, all treatments provided ≥ 94% barnyardgrass control. At 6 weeks after the postemergence application, mixtures of clomazone and oxyfluorfen provided 95% or greater barnyardgrass control. Conversely, when sequential applications of oxyfluorfen alone were made, regardless of rate, barnyardgrass control was only 77% and 79% at 6 weeks after the postemergence application. When clomazone and oxyfluorfen were applied at a 1:3 ratio and 1:2 ratio or clomazone alone applied at 0.3 lb ai/ac, rice yields were comparable among treatments, ranging from 106 to 130 bu./ac. Treatments of oxyfluorfen at 0.6 and 0.75 lb ai/ac, and clomazone at 0.25 lb ai/ac, resulted in rice yields of 74 to 93 bu./ac. These results indicate that clomazone will likely be needed with oxyfluorfen to obtain extended residual barnyardgrass control in the RRPS.

Introduction

Barnyardgrass [*Echinochloa crus-galli* (L.) P. Beauv.] is a common weed in both flooded and furrow-irrigated rice cropping systems and is the most problematic weed in Arkansas rice (*Oryza sativa* L.) production (Butts et al., 2022). In a rice production system, barnyardgrass can reduce grain yield by 70% if left uncontrolled for the entire growing season (Smith Jr., 1968). In Arkansas, barnyardgrass is resistant to six HRAC/WSSA classified modes of action; Group 1, Group 2, Group 4, Group 5, Group 13, and Group 29 (Heap, 2023; Barber et al.2023). Herbicide resistance makes controlling barnyardgrass difficult for Arkansas rice producers and impacts the producer's profit. Oxyfluorfen is a HRAC/WSSA group 14 protoporphyrinogen oxidase (PPO) inhibiting herbicide used in row crops, such as, cotton and soybean, as well as some tree and vegetable species to control barnyardgrass and other grass species (WSSA, 2022). Currently, there are no HRAC/WSSA group 14 herbicides labeled for control of barnyardgrass in rice. The development of Roxy rice provides resistance to oxyfluorfen, possibly providing another mode of action for barnyardgrass control in rice. Therefore, an experiment was conducted to evaluate the impact of oxyfluorfen on barnyardgrass control.

Procedures

A field experiment was conducted in 2022, at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center near Stuttgart, Arkansas, to evaluate various rates of clomazone and oxyfluorfen alone and in combination for residual barnyardgrass control. The experiment was designed to determine if any ratio of clomazone and oxyfluorfen provided comparable or better control than clomazone or oxyfluorfen alone. An oxyfluorfen-resistant cultivar was drill seeded at 22 seed/ft and plot dimensions were 6 ft wide by 17 ft long. The trial was designed as a single factor randomized complete block with 7 treatments and 4 replications. All treatments were applied preemergence and the same treatment was sequentially applied postemergence at the 2-leaf rice growth stage. Clomazone alone was applied at 0.25 lb ai/ac and 0.3 lb ai/ac, oxyfluorfen alone at 0.6 lb ai/ac and 0.75 lb ai/ac and mixtures of clomazone and oxyfluorfen were applied at a 1:3 ratio (0.25 lb and 0.75 lb ai/ac) and a 1:2 ratio (0.3 lb and 0.6 lb ai/ac). Applications were made using a CO_2-pressurized backpack sprayer using AIXR 110015 nozzles calibrated to deliver 15 gal/ac. Visual control ratings of barnyardgrass were taken weekly after treatment. Weed control was visually rated on a scale from

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0% to 100%, with a rating of 0% being no control and 100% being complete control. Data were subjected to analysis of variance and means were separated using Fisher's protected least significant difference with an alpha value of 0.05.

Results and Discussion

At 3 weeks after the preemergence application of clomazone, the mixtures of clomazone and oxyfluorfen, and oxyfluorfen at the rate of 0.6 lb ai/ac provided comparable visual control of barnyardgrass (≥94%), with both rates of the mixture providing 100% control (Table 1). The high rate of oxyfluorfen alone provided comparable control to oxyfluorfen at 0.6 lb ai/ac and clomazone at 0.25 lb ai/ac. The preemergence application of oxyfluorfen alone provided greater than 90% barnyardgrass control; however, if oxyfluorfen were to become labeled in rice, it would be recommended to apply a mixture of clomazone and oxyfluorfen to provide better control and add an additional mode of action to preemergence applications.

At 1 week after the postemergence application, all treatments provided 100% control of barnyardgrass; however, by 3 weeks after the postemergence application, all treatments provided ≥ 95% control. Barnyardgrass control at 5 weeks after the postemergence application for all treatments was 100%, except clomazone alone at 0.25 lb ai/ac which provided 94% control. At 6 weeks after the postemergence application, clomazone at 0.3 lb ai/ac and the mixtures of clomazone and oxyfluorfen provided ≥95% control of barnyardgrass. Clomazone at 0.25 lb ai/ac, oxyfluorfen at 0.6 lb ai/ac, and 0.75 lb ai/ac provided 83, 79, and 77% control of barnyardgrass, respectively (Table 1).

Practical Applications

If oxyfluorfen were to become labeled, a mixture of clomazone and oxyfluorfen would likely be recommended over clomazone or oxyfluorfen alone. If labeled, oxyfluorfen could provide rice producers with an additional mode of action for barnyardgrass control and help to control troublesome herbicide-resistant barnyardgrass.

Acknowledgments

The authors would like to thank the Arkansas Rice Check-off Program for providing funding for this research administered by the Arkansas Rice Research and Promotion Board as well as the University of Arkansas System Division of Agriculture, the Rice Research and Extension Center in Stuttgart, and Albaugh Company for support of this weed control research in rice.

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Table 1. Visual barnyardgrass control 3 weeks after preemergence treatment (WAPRE) and 5 and 6 weeks after 2-leaf treatment (WAPOST) from 2022, near Stuttgart, Arkansas.[a]

		Control		
Treatment	**Rate**	**3 WAPRE**	**5 WAPOST**	**6 WAPOST**
	lb ai/ac	----------------	%	----------------
Clomazone	0.25	94 ab	94 a	83 abc
	0.3	99 a	100 a	96 a
Oxyfluorfen	0.6	97 ab	100 a	78 bc
	0.75	93 b	100 a	77 c
Clomazone +	0.3 + 0.6	100 a	100 a	95 ab
Oxyfluorfen	0.25 + 0.75	100 a	100 a	95 ab

[a] Means within a column followed by the same letter are not different according to Fisher's protected least significant difference (α = 0.05).

Influence of Application Timing on Rice Tolerance to Fluridone

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Abstract

Widespread herbicide resistance is an issue in rice (*Oryza sativa* L.) due to the difficult control of the resistant weeds, making weed management challenging for farmers. Therefore, research of new modes of action to control herbicide-resistant weeds must also include evaluations of crop safety. Fluridone was tested for potential weed control in rice; however, little is known regarding the optimum application timing to reduce crop response. Therefore, this study aimed to evaluate the influence of fluridone application timing on rice tolerance. The experiment was conducted in 2022 at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center near Stuttgart, Ark. The experiment was organized as a randomized complete block with 10 application timings and 4 replications. The application timings were: 22 and 11 days preplant, preemergence (PRE), delayed-preemergence (DPRE), 1-leaf, 2-leaf, 3-leaf, 4-leaf, preflood, and immediately after flood establishment (post-flood). Nontreated control plots were included for comparison. Fluridone was applied at 0.15 lb/ac in all treatments. Visual rice injury and ground cover were collected 35 and 70 days after emergence (DAE), and rough rice yield was collected at maturity. At 35 DAE, PRE and DPRE treatments caused 13% and 11% visible injury, respectively. However, by 70 DAE, crop injury increased following the establishment of the flood, reaching 40% for both the PRE and DPRE treatments. Canopy loss occurred at 35 and 70 DAE for the PRE treatment compared to the nontreated control. Rice exhibited a high tolerance level to a post-flood fluridone application, comparable to the nontreated control. However, at the application timings PRE, DPRE, and 1-leaf, rough rice yield was lower than in plots where fluridone was not applied. Further research on rice tolerance to fluridone is needed over a wide range of environments as well as quantifying the weed control value of fluridone in drill-seeded rice culture.

Introduction

Herbicide resistance is a major issue that contributes to significant rice yield loss due to the increased difficulty of controlling these weeds. In addition, the low number of herbicides labeled for rice production in the mid-southern U.S. worsens this problem, and the loss of any rice herbicide only causes more concerns (Norsworthy et al., 2013). New modes of action are needed in the rice herbicide portfolio in an effort to control herbicide-resistant weeds and avoid new cases of resistance.

Fluridone, a HRAC/WSSA Group 12 herbicide, has been tested for potential weed control in rice; however, little is known regarding the best application timing. Currently, this herbicide is registered for aquatic weed control and labeled for use in cotton (*Gossypium hirsutum* L.) for control of a wide range of annual grass and broadleaf weeds (Waldrep and Taylor, 1976; Goggin and Powles, 2014). Because of its persistence in the soil, injury to crops other than cotton may occur, but injury levels can vary depending on application timing (Hill et al., 2016). For instance, fluridone is more active when applied in preemergence compared to foliar applications (Waldrep and Taylor, 1976).

It is necessary to add new chemicals to existing rice herbicide programs. The objective of this study was to evaluate the influence of fluridone application timing on rice tolerance as a potential new chemical option to be added to the rice herbicide portfolio.

Procedures

A field experiment was conducted during the 2022 rice growing season at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC) near Stuttgart, Ark. The field was drill-seeded with a long-grain, Provisia® rice variety (PVL02) at a rate of 22 seeds/row ft and a depth of 0.5 in. The plots were 6 ft wide by 17 ft long. The field trial was organized as a randomized complete block with 10 application timings and a nontreated control as a comparison. Each treatment had 4 replications. Fluridone (Brake 2L, SePRO Corporation, 11550 North Meridian Street Suite 600, Carmel, Ind.) was applied at 0.15 lb/ac at the following application timings: 22 and 11 days preplant, preemergence (PRE), delayed-preemergence (DPRE), 1-leaf, 2-leaf, 3-leaf, 4-leaf, preflood, and post-flood (this treatment was applied one day after the permanent flood was established). The trial was maintained as a weed-free trial using standard herbicides labeled in rice to avoid other interference on the crop other than treatment impacts. The herbicides were applied with a 4-nozzle backpack sprayer propelled by CO_2 using AIXR 110015 nozzles at 3 mph delivering 15 GPA. Rainfall data were collected from a weather station 700 ft away from the site. Visual crop injury and rice ground cover were collected 35 and 70 days after emergence (DAE). Visual injury was rated on a scale of 0 to 100, with 0 being no injury and 100 being plant mortality (Frans et al., 1986). Rice

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groundcover was estimated using small unmanned aerial system (sUAS) images in the TurfAnalyzer program. Rough rice grain yield was determined at crop maturity. Data were subjected to analysis of variance in JMP Pro 16.2 (SAS Institute, In., Cary, N.C.), and means were separated using Fisher's protected least significant difference with an alpha level of 0.05.

Results and Discussion

Fluridone was water-activated following the permanent flood, which increased injury over time, with the highest levels present at 70 DAE. There was a difference in injury among the treatments at 35 DAE and 70 DAE ($P < 0.0001$). At 35 DAE, the greatest injury levels were observed on PRE and DPRE treatments, with 13% and 11%, respectively (Table 1). At 70 DAE, the injury was accentuated, reaching 40% for the PRE and DPRE treatments (Table 1). According to Waldrep and Taylor (1976), soil-applied fluridone results in higher injury than postemergence applications. Similar results were obtained in this study, where the early applications (PRE and DPRE) caused the greatest injury to rice. However, fluridone applied in preplant applications did not translate to a high level of injury. Rainfall accumulation of 1.93 inches occurred between the first preplant application and the planting date. As a result, the treated plots were lightly tilled to facilitate planting, which in turn may have minimized the injury caused by the two preplant treatments.

Differences were also observed among the rice groundcover ratings (35 DAE: $P = 0.0183$; 70 DAE: $P = 0.0458$). At 35 and 70 DAE evaluation timings, greater rice canopy loss occurred from the PRE treatment (83% and 91%, respectively) compared to the nontreated control (Table 1). These results were associated with crop injury, predominately bleaching, which is characteristic of fluridone.

Rice yield was lower than the nontreated control as a result of the PRE, DPRE, and 1-leaf treatments ($P = 0.0010$; Table 1). The numerically highest yield was obtained following the post-flood application of fluridone, which averaged 144 bu./ac (Table 1).

Practical Applications

Fluridone has the potential to be added to the rice herbicide portfolio, targeting late postemergence applications. The late applications (preflood and post-flood) resulted in low injury levels with no yield penalties. The addition of this herbicide to the rice weed control program would offer a new mode of action to be rotated with the herbicides already labeled, contributing to the tactics to avoid herbicide resistance.

Acknowledgments

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Table 1. Visible injury and groundcover of Provisia® rice at 35 and 70 days after emergence (DAE) and rough rice grain yield as influenced by fluridone application timings.

		Visible injury		Groundcover		
Treatment	Application timing[†]	35 DAE[‡]	70 DAE	35 DAE	70 DAE	Grain yield
		------------------------------	------------------------------(%)------------------------------		------------------------------	(bu./ac)
1	Nontreated	--	--	97 a	98 ab	124 ab
2	21 days preplant	5 bc[§]	20 cde	92 a	98 ab	120 bc
3	14 days preplant	5 bc	15 e	94 a	98 ab	123 b
4	PRE[¶]	13 a	40 a	83 b	91 c	104 cd
5	DPRE[#]	11 a	40 a	92 a	95 abc	101 d
6	1-leaf	6 b	29 bc	95 a	94 bc	104 cd
7	2-leaf	4 bc	26 cd	92 a	98 ab	109 bcd
8	3-leaf	4 bc	26 cd	95 a	98 ab	109 bcd
9	4-leaf	3 bc	18 ed	94 a	99 a	119 bcd
10	Preflood	2 bc	16 e	93 a	99 a	127 ab
11	Post-flood	1 c	11 e	95 a	99 a	144 a

[†] All treatments, except for the nontreated control, were sprayed with fluridone at 0.15 lb/ac.
[‡] DAE = days after emergence.
[§] Means followed by the same letter within a column are not different according to Fisher's protected least significant difference with α = 0.05.
[¶] PRE = preemergence.
[#] DPRE = delayed-preemergence.

Rice Response to Low Concentrations of Diflufenican

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Abstract

Palmer amaranth [*Amaranthus palmeri* (S.) Wats] is one of the most problematic weed species across multiple cropping systems in Arkansas. Palmer amaranth is resistant to nine modes of action, making the weed difficult for producers to control. Diflufenican (DFF) is a Weed Seed Science Society of America (WSSA) group 12 herbicide that will likely be labeled for use in soybean. Although DFF is targeted for use in soybean, additional research is being conducted to evaluate the potential for the herbicide to carryover and injure common rotational crops. Therefore, an experiment was conducted at the Rice Research and Extension Center near Stuttgart, AR, to evaluate the sensitivity of rice (*Oryza sativa* L.) to low concentrations of DFF in the soil. Applications of DFF were applied preemergence (PRE) at 0.0065, 0.0125, 0.25, 0.5, and 1.0 times the anticipated 1X rate. By 2 weeks after emergence (WAE), the highest injury observed was 20% when a 1X rate was applied, and injury decreased as the rate of DFF decreased. Rice shoot counts were taken 2 WAE and no differnences were observed between treatments. By 5 WAE, less than 5% injury was observed in all treatments evaluated. Grain yield was collected at maturity, and no differences were observed among treatments. Overall, there does not appear to be a high risk for herbicide carryover to rice from soybean that received an application of DFF during the previous growing season.

Introduction

Palmer amaranth [*Amaranthus palmeri* (S.) Wats.] is the most problematic weed in soybean [*Glycine max* (L.) Merr.], cotton (*Gossypium hirsutum* L.), and corn (*Zea mays* L.) production (Van Wychen 2022). In a flooded rice (*Oryza sativa* L.) production system, Palmer amaranth is not the most problematic weed, but over the past seven years there has been a shift towards a furrow-irrigated rice production system, which has allowed for a shift in the weed spectrum (Barber et al. 2020). A survey conducted in the fall of 2022 showed that Palmer amaranth was the second most problematic weed in furrow-irrigated rice (Butts et al. 2022). Palmer amaranth has become a problematic weed across various cropping systems partly due to its resistance to many herbicides. Currently, Palmer amaranth has developed resistance to nine modes of action (Heap 2023), leaving producers with limited chemical control options for this weed. Therefore, Bayer CropScience has announced its intent to register diflufenican (DFF) for preemergence (PRE) use in soybean. Diflufenican is a Weed Seed Science Society of America (WSSA) group 12 herbicide that would give producers an additional mode of action for Palmer amaranth control in soybean (Anonymous, 2021). While DFF is intended to be used in soybean production, further research is needed to evaluate if DFF has the potential to carry over and injure common rotational crops such as rice.

Procedures

A field experiment was conducted in 2022 at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center near Stuttgart, Arkansas, to determine rice sensitivity to low concentrations of DFF in the soil. A quizalofop-P-resistant cultivar (PVL03) was drill-seeded at 22 seed/ft of row in 7.5-in. wide rows, and plots were 6 ft wide by 17 ft long. The trial was irrigated using standard flooded rice methods in Arkansas. A broadcast application of Command® 3ME at 12.8 fl oz/ac and Roundup PowerMAX® 3 at 30 fl oz/ac were applied preemergence (PRE), and standard rice herbicides were used throughout the growing season to control weeds. The trial was designed as a randomized complete block with one factor (DFF rate) and four replications. The DFF rates evaluated were applied to the rice PRE at 0.0065, 0.125, 0.25, 0.50, and 1.0 times the 1X anticipated labeled rate. All applications were made at 3 mph with a CO_2-pressurized backpack sprayer calibrated to deliver 15 GPA using AIXR 110015 nozzles. Visible injury ratings were evaluated weekly from 2 to 6 weeks after emergence. Injury was rated on a scale from 0% to 100%, with 0 being no crop injury and 100 being complete crop death. Rice shoot counts were collected 2 weeks after emergence (WAE), and rough rice yields were collected at maturity. Data were subjected to an analysis of variance, and means were separated using Fisher's protected least significant difference with an alpha value of 0.05.

Results and Discussion

By 2 WAE, injury ranged from 8% to 20% over the DFF rates tested (Table 1). As the rate of DFF applied decreased, there was a decrease in injury observed. By 5 WAE, rice was injured less than 5% by all DFF treatments evaluated. At 6 WAE, there was no injury to rice for any treatment. Rice shoot counts were collected 2 WAE to determine if DFF influenced the number of shoots. Rice shoot production was not negatively affected by any of the DFF rates evaluated, ranging from 30 to 36 shoots per 3.3

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ft of row (Table 2). Similarly, there were no differences in rough rice grain yield, with treatment averages being 161 to 172 bu/ac (Table 2). Overall, there seems to be minimal risk for DFF to carry over from soybean to rice.

Practical Applications

Registration of DFF as a WSSA group 12 herbicide for use in soybean should pose minimal risk to rice producers in the mid-southern United States in terms of carryover. Even a 1X rate of DFF did not cause reductions in stand loss or rough rice grain yield. In addition to carryover, research is needed to determine the risk for rice injury caused by DFF drift from adjacent soybean fields, especially considering that soybean is commonly planted after rice emergence.

Acknowledgments

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Table 1. Rice injury 2, 5, and 6 weeks after emergence (WAE) following a preemergence (PRE) application of diflufenican in 2022 at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center near Stuttgart, Ark.

Timing	Diflufenican rate	Injury 2 WAE	Injury 5 WAE	Injury 6 WAE
		---%	---	---
PRE	1x	20 a[†]	2	0
PRE	0.5X	18 a	4	0
PRE	0.25X	13 b	2	0
PRE	0.125X	10 c	2	0
PRE	0.0065	8 c	2	0

[†] Means within a column followed by the same letter are not different according to Fisher's protected least significant difference ($\alpha = 0.05$).

Table 2. Rice shoot density at 2 weeks after rice emergence and rough rice grain yield for 2022 at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center near Stuttgart, Ark.

Diflufenican rate	Rice shoot density[†]	Rough rice yield[†]
	# per 3.3 ft of row	bu./ac
1x	30	171
0.5X	33	161
0.25X	35	172
0.125X	36	164
0.0065X	35	165
0X	36	162

[†] There were no statistical differences in shoot density or rough rice yield among treatments.

Arkansas Rice Performance Trials, 2022

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Abstract

Use of on-farm commercial fields and research stations provides the opportunity to evaluate cultivar performance across a wide range of environmental conditions and management situations. The Arkansas Rice Performance Trials (ARPT) utilize experiment stations and commercial fields throughout the rice-producing regions of Arkansas to evaluate the performance of commercial rice cultivars. These trials provide information on agronomic factors of cultivars such as disease resistance, lodging, plant stand, plant height, grain yield, and milling yield across a range of environmental conditions, growing practices, and soil types. Choosing a cultivar is a critical decision annually for producers. Studies in 2022 were in grower fields in Clay, Desha, Greene, Jackson, Lawrence, and Lonoke counties, and on research stations in Arkansas, Mississippi, Poinsett, and St. Francis counties. The average grain yield across all 10 trials was 176 bu./ac with the highest average yielding location being Arkansas County at 191 bu./ac. Cultivars that had the highest average grain yield across all locations include RT XP780, RT 7521 FP, RT 7401, RT XP753, RT 7302, RT 7331 MA, Ozark, and DG263L. The average milling yield across all cultivars was 56/70 (%HR/%TR), with Addi Jo, Jupiter, Leland, DGL2065, and CLM04 producing the highest average milling yields.

Introduction

The University of Arkansas System Division of Agriculture (UADA) strives to provide well-rounded research to growers when choosing commercially available rice cultivars. Information provided is potential grain and milling yields, disease susceptibility, and yearly fertilizer recommendations. This information is supported by the Degree-Day 50 (DD50) Rice Management Program in providing thresholds. Each trial faces other factors that can influence grain yield, and these include seeding date and rate, water quality, disease pressure, weather events, and a variety of other cultural management practices determined by the grower.

Profitability from rice fields in Arkansas can be affected by diseases. Disease is best managed when considering ideal farming practices, host-plant resistance, and integrated pest management (for fungicide) to minimize loss of profit proportional to the quality of rice. Cultivars that are resistant to disease can maximize profits by aiming to reduce disease control costs by lower fungicide applications.

New rice cultivars are developed and evaluated annually at research station locations that are managed by UADA staff. Large amounts of data are garnered from these trials which provide grain yield and quality, growth behavior, and disease resistance. While this information gained is useful, it does not consider environment and management variability, which can be provided by on-farm locations. Field research from both a controlled and uncontrolled setting provides growers with information that benefits them in making informed decisions when choosing a cultivar.

The Arkansas Rice Performance Trials (ARPT) are designed to challenge cultivars across various areas of Arkansas. They are also useful in providing hands-on and educational opportunities to county agents, consultants, and producers.

The objectives of the ARPT are to 1) compare the potential yield of available commercial cultivars and advanced experimental lines on fields used for commercial production; 2) monitor disease pressure in different regions of Arkansas; and 3) evaluate performances of rice cultivars under differing conditions from experiment stations.

Procedures

For the 2022 season, trial locations were in Arkansas, St. Francis, Mississippi, Poinsett, Clay, Desha, Lawrence, Jackson, Greene, and Lonoke counties. A total of 30 cultivars were evaluated at each location. Entries included the conventional (non-herbicide-tolerant) long-grain varieties Addi Jo, Avant, DG263L, DGL037, DGL2065, Diamond, Leland, Ozark, ProGold1, and ProGold2; the conventional medium-grain varieties DG353M, Jupiter, Taurus, and Titan; the Clearfield long-grain varieties CLL16, CLL17, CLL18, and CLL19; the Clearfield medium-grain variety CLM04; the

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Provisia long-grain variety PVL03; the MaxAce long-grain variety RTv7231 MA; the MaxAce long-grain hybrid RT 7331 MA; the FullPage long-grain hybrids RT 7321 FP, RT 7421 FP, and RT 7521 FP; and the conventional long-grain hybrids RT 7302, RT 7401, RT XP753, and RT XP780.

Plots were 8 rows (7.5-in. spacing) wide and 17.5-ft in length with a randomized complete block design with 4 replications. Pureline cultivars (varieties) were seeded at 33 seeds/ft^2 with hybrids seeded at 11 seeds/ft^2. All seed was treated with an insecticide and fungicide seed treatment package. Trials were seeded 29 March (Arkansas), 9 May (St. Francis), 18 May (Mississippi), 28 April (Poinsett), 28 April (Clay), 20 May (Desha), 10 May (Lawrence), 11 May (Jackson), 5 May (Greene), and 11 May (Lonoke) (Table 1). All plots were managed with a conventional herbicide program.

ARPT locations had some cultural practice variations but overall were grown for highest yield. Trials planted at on-farm locations were managed by the growers' cultural practice: irrigation, fertilization, fungicide application, and weed and insect control. Disease rating also took into consideration fungicide applications with periodic inspecting to grade disease. At harvest lodging notes were recorded. Once plots achieved maturity, weight and moisture of each plot were recorded and used to calculate yield in bushels per acre (bu./ac) adjusted to 12% moisture dry weight. A bushel of rice weighs 45 lbs. A sample was collected from each plot to evaluate milling. The dried rice sample was milled to procure percent head rice (%HR, whole kernels) and a total percent white rice (%TR) to provide milling yield expressed as %HR/%TR. Data were analyzed using analysis of variance, PROC GLM, SAS v. 9.4 (SAS Institute, Inc., N.C.) with means separated using Fisher's least significant difference test ($P = 0.05$).

Results and Discussion

All trial locations in the 2022 growing season had all 30 cultivars represented. Table 1 provides a summary of agronomic information related to each trial location. The grain yield average across all locations was 191 bu./ac (Table 2). The highest-yielding cultivars across all locations were RT XP780, RT 7521 FP, RT 7401, RT XP753, RT 7302, RT 7331 MA, Ozark, and DG263L.

At Arkansas Co., the overall grain yield average was 191 bu./ac across all cultivars (Table 3). The highest yielding hybrids were RT 7302 and RT XP780 while the highest-yielding varieties were Ozark and DGL037. The site had an average milling yield of 62/70 (%HR/%TR) with Leland, DGL2065, and Jupiter resulting in the highest milling yields.

The St. Francis Co. location had an average grain yield of 154 bu./ac, which was the lowest yield for any trial in 2022 (Table 4). The highest-yielding hybrids were RT 7521 FP and RT XP780 while the highest-yielding varieties were DG263L and DGL037. The St. Francis Co. location had an average milling yield of 35/68 (%HR/%TR). The highest milling yield entries are DGL2065 and Addi Jo.

The trial at Mississippi Co. had an average grain yield of 171 bu./ac (Table 5). Hybrids with the highest grain yields were RT XP780 and RT XP753 and varieties with the highest grain yields were Ozark and CLL18. This location had a milling yield of 56/71 (%HR/%TR). The highest milling entries were Ozark and ProGold1.

The trial at Poinsett Co. had an average grain yield of 186 bu./ac (Table 6). The highest-yielding hybrids were RT 7401 and RT 7521 FP and the highest-yielding varieties were Taurus and Ozark. The average milling yield of this trial was 65/72 (%HR/%TR). Entries that provided the highest milling yields were RT XP753, RT 7302, and CLM04.

The Clay Co. location was an on-farm trial with a grain yield average of 185 bu./ac (Table 7). The highest-yielding hybrid entries were RT 7521 FP and RT 7302 while the highest-yield variety entries were RTv7231 MA and DG263L. This average milling yield of 63/70 (%HR/%TR). Cultivars with the highest milling yields included Titan and CLM04.

The on-farm location in Desha Co. yielded an average of 178 bu./ac (Table 8). Hybrid entries with the highest grain yields were RT 7521 FP and RT 7421 FP and variety entries with the highest grain yields were CLL19 and Ozark. This location had an average milling yield of 61/72 (%HR/%TR). The highest milling yielding entries were Jupiter and Leland.

Lawrence Co. was an on-farm location with an average grain yield of 170 bu./ac (Table 9). The hybrid entries with the highest grain yields were RT 7302 and RTXP780 and the variety entries with the highest grain yields were Taurus and DG263L. The milling yield average for this location was 56/69 (%HR/%TR). Cultivars with the highest milling yields were Leland and Jupiter.

The Jackson Co. on-farm location produced grain yields of 168 bu./ac (Table 10). Cultivars with the highest yields at this location for hybrids were RT 7521 FP and RT XP780 and for varieties were Ozark and DGL037. The average milling yield was 60/72 (%HR/%TR) for this location. The highest milling yields were Ozark, Jupiter, and CLM04.

The on-farm location in Greene Co. had an average grain yield of 168 bu./ac (Table 11). The highest-yielding hybrid entries were RT 7401 and RT XP753 and the highest-yield variety entries were DGL037 and Ozark. Greene Co. had a milling yield of 53/70 (%HR/%TR). The highest milling cultivars were Addi Jo and Leland.

The Lonoke Co. on-farm location produced an average grain yield of 180 bu./ac (Table 12). Entries that yielded the highest for hybrids were RTXP780 and RT XP753 and for varieties were DG263L and Taurus. The average milling yield at Lonoke Co. was 48/71 (%HR/%TR). The cultivars with the highest milling were Jupiter and CLM04.

Practical Applications

Additional data from the 2022 Arkansas Performance Rice Trials helped rice breeding and disease resistance programs. The 2022 trials also provided delivered additional supplemental data on performance and disease reaction on new (and older) cultivars that may be increasingly raised on rice acres in Arkansas during 2022.

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Table 1. Cultural Data Summary for 2022 Arkansas Rice Performance Trials.

County	City	Soil Class	Planting Date	Emergence Date	Harvest Date
Arkansas	Stuttgart	Dewitt silt loam	3/29	4/15	9/7
St. Francis	Colt	Calhoun-Henry silt loam	5/9	5/15	9/27
Mississippi	Keiser	Sharkey silty clay	5/18	5/25	10/13
Poinsett	Harrisburg	Calloway-Henry silt loam	4/28	5/6	10/13
Clay	McDougal	Crowley silt loam/ Jackport silty clay	4/28	5/11	9/14
Desha	Dumas	Rilla silt loam/ Portland clay	5/20	5/28	9/28
Lawrence	Walnut Ridge	Foley-Calhoun silt loam	5/10	5/18	9/21
Jackson	Newport	Amagon/ Forestdale silt loam	5/11	5/28	9/29
Greene	Paragould	Jackport silty clay loam	5/11	5/17	9/21
Lonoke	England	Portland silty clay	5/11	5/18	9/12

Table 2. Results of the Arkansas Performance Rice Trials (ARPT) at 10 Locations during 2022.

Cultivar	Grain Type[a]	Lodging[b]	Milling Yield[c]	Grain Yield by Location and Planting Date										
				ARK[d]	STF	MIS	POI	CLA	DES	LAW	JACK	GRE	LON	Mean
		(%)	(%HR/%TR)	(bu./ac)										
Addi Jo	L	2	62/70	157	129	107	157	162	163	127	154	144	149	149
Avant	L	1	59/71	173	173	184	167	171	185	163	147	168	185	170
DG263L	L	8	51/69	191	194	162	184	211	166	188	155	181	222	188
DGL037	L	6	56/69	206	178	173	174	192	176	173	181	195	186	185
DGL2065	L	1	62/71	190	158	173	164	162	173	151	154	163	181	166
Diamond	L	2	58/71	180	150	186	179	170	179	167	159	163	183	170
Leland	L	0	62/72	180	147	164	170	155	153	155	168	156	173	162
Ozark	L	3	61/71	207	177	196	196	190	186	185	181	190	188	189
ProGold1	L	2	56/70	174	151	184	180	171	177	156	158	171	182	169
ProGold2	L	1	53/71	190	142	166	167	154	180	156	159	161	168	164
CLHA02	CL	2	56/70	172	153	186	161	186	175	136	143	164	183	164
CLL16	CL	2	56/70	181	160	181	178	168	169	167	167	168	193	172
CLL17	CL	8	59/70	172	161	148	154	171	164	137	126	136	179	155
CLL18	CL	2	58/69	189	157	188	186	180	185	179	166	168	192	178
CLL19	CL	0	59/70	193	154	181	183	197	199	176	154	167	185	179
PVL03	PL	0	58/71	177	135	165	163	171	173	147	150	164	182	162
RTv7231 MA	ML	12	48/70	202	137	168	187	211	180	186	174	152	195	181
RT 7331 MA	MLH	17	51/71	220	138	190	225	205	184	201	169	189	186	191
RT 7321 FP	FLH	18	47/71	210	125	193	196	203	160	159	179	171	178	176
RT 7421 FP	FLH	31	51/71	211	147	137	218	194	211	181	198	164	167	188
RT 7521 FP	FLH	27	57/70	211	187	132	228	226	221	181	223	161	187	203
RT 7302	LH	26	52/72	222	149	181	216	225	197	210	205	184	165	197
RT 7401	LH	23	52/71	211	158	174	234	214	200	200	203	204	173	200
RT XP753	LH	4	49/72	219	168	210	220	194	197	207	192	203	191	199
RT XP780	LH	6	55/70	221	180	224	225	217	203	209	214	187	196	206

Table 2. Continued.

Cultivar	Grain Type[a]	Lodging[b]	Milling Yield[c]	Grain Yield by Location and Planting Date ARK[d]	STF	MIS	POI	CLA	DES	LAW	JACK	GRE	LON	Mean
		(%)	(%HR/%TR)	(bu./ac)										
DG353M	M	1	57/70	172	146	136	166	172	169	146	155	150	165	160
Jupiter	M	4	62/69	168	131	152	165	163	135	147	142	147	157	150
Titan	M	2	56/70	166	132	160	173	182	150	159	136	149	153	156
Taurus	M	4	62/70	193	154	164	203	182	184	189	170	168	200	183
CLM04	CM	12	62/70	172	146	136	166	172	169	149	155	150	165	160
Mean		8	56/70	191	154	171	186	185	178	170	168	168	180	176
$LSD_{0.05}$[e]		6	2/1	16	15	25	16	17	18	19	14	23	19	6

[a] Grain type: L = long-grain; CL = Clearfield long-grain; PL = Provisia long-grain; ML = MaxAce long-grain; MLH = MaxAce long-grain hybrid; FLH = FullPage long-grain hybrid; LH = long-grain hybrid; M = medium-grain; CM = Clearfield medium-grain.

[b] Lodging = % of plot down at harvest.

[c] Milling yield = % Head Rice/% Total Rice.

[d] ARK = Arkansas Co., Rice Research and Extension Center, Stuttgart, Ark.; STF = St. Francis Co., Pine Tree Research Station, Colt, Ark.; MIS = Mississippi Co., Northeast Research and Extension Center, Keiser, Ark.; Poinsett Co., Northeast Rice Research and Extension Center, Harrisburg, Ark.; CLA = Clay Co., producer field near McDougal, Ark.; DES = Desha Co., producer field near Dumas, Ark.; LAW = Lawrence Co., producer field near Walnut Ridge, Ark.; JAC = Jackson Co., producer field near Newport, Ark.; GRE = Greene Co.; producer field near Paragould, Ark.; LON = Lonoke Co., producer field near England, Ark.

[e] LSD = least significant difference.

Table 3. Results of Arkansas County Arkansas Rice Performance Trial (ARPT) during 2022 (planted 29 March; harvested 7 September).

Cultivar	Grain Type[a]	Lodging[b]	Moisture[c]	Grain Yield	Milling Yield
		(%)	(%)	(bu./ac)	(%HR/%TR)
Addi Jo	L	0	18	157	64/70
Avant	L	0	16	173	63/70
DG263L	L	0	16	191	58/68
DGL037	L	0	19	206	59/69
DGL2065	L	0	17	190	65/71
Diamond	L	0	17	180	62/70
Leland	L	0	17	180	66/72
Ozark	L	6	16	207	62/70
ProGold1	L	0	17	174	60/69
ProGold2	L	0	16	190	64/71
CLHA02	CL	0	15	172	62/70
CLL16	CL	0	19	181	61/69
CLL17	CL	10	15	172	61/69
CLL18	CL	0	17	189	59/68
CLL19	CL	0	15	193	61/69
PVL03	PL	0	15	177	64/71
RTv7231 MA	ML	0	16	202	56/68
RT 7331 MA	MLH	0	14	220	63/71
RT 7321 FP	FLH	0	14	210	58/70
RT 7421 FP	FLH	0	15	211	61/71
RT 7521 FP	FLH	4	16	211	61/70
RT 7302	LH	0	15	222	62/71
RT 7401	LH	0	14	211	61/71
RT XP753	LH	3	15	219	63/71
RT XP780	LH	0	17	221	61/69
DG353M	M	0	16	155	63/69
Jupiter	M	0	19	168	65/69
Taurus	M	0	16	193	61/69
Titan	M	0	15	166	62/69
CLM04	CM	0	17	172	65/70
Mean	–	1	16	191	62/70
$LSD_{0.05}$[e]	–	4	1	16	3/1

[a] Grain type: L = long-grain; CL = Clearfield long-grain; PL = Provisia long-grain; ML = MaxAce long-grain; MLH = MaxAce long-grain hybrid; FLH = FullPage long-grain hybrid; LH = long-grain hybrid; M = medium-grain; CM = Clearfield medium-grain.

[b] Lodging = % of plot down at harvest.

[c] Grain moisture at harvest.

[d] Milling yield = % Head Rice/% Total Rice.

[e] LSD = least significant difference.

Table 4. Results of St. Francis County Arkansas Rice Performance Trial (ARPT) during 2022 (planted 9 May; harvested 27 September).

Cultivar	Grain Type[a]	Lodging[b]	Moisture[c]	Grain Yield	Milling Yield
		(%)	(%)	(bu./ac)	(%HR/%TR)
Addi Jo	L	15	15	129	57/68
Avant	L	0	12	173	46/69
DG263L	L	13	10	194	32/67
DGL037	L	0	12	178	38/66
DGL2065	L	0	12	158	50/70
Diamond	L	19	13	150	45/69
Leland	L	0	12	147	47/70
Ozark	L	0	12	177	48/69
ProGold1	L	0	12	151	31/68
ProGold2	L	0	12	142	26/69
CLHA02	CL	0	12	153	36/68
CLL16	CL	0	14	160	40/68
CLL17	CL	0	12	161	47/68
CLL18	CL	0	12	157	43/67
CLL19	CL	0	11	154	45/68
PVL03	PL	0	11	135	42/69
RTv7231 MA	ML	58	10	137	14/69
RT 7331 MA	MLH	39	9	138	21/59
RT 7321 FP	FLH	64	10	125	19/69
RT 7421 FP	FLH	44	11	147	25/69
RT 7521 FP	FLH	0	10	187	43/67
RT 7302	LH	83	11	149	22/69
RT 7401	LH	18	9	158	29/69
RT XP753	LH	86	10	168	23/69
RT XP780	LH	0	12	180	33/68
DG353M	M	0	12	151	29/68
Jupiter	M	0	16	131	46/66
Taurus	M	0	12	154	27/69
Titan	M	0	11	132	18/68
CLM04	CM	0	13	146	39/68
Mean	–	15	12	154	35/68
$LSD_{0.05}$[e]	–	25	1	15	7/6

[a] Grain type: L = long-grain; CL = Clearfield long-grain; PL = Provisia long-grain; ML = MaxAce long-grain; MLH = MaxAce long-grain hybrid; FLH = FullPage long-grain hybrid; LH = long-grain hybrid; M = medium-grain; CM = Clearfield medium-grain.

[b] Lodging = % of plot down at harvest.

[c] Grain moisture at harvest.

[d] Milling yield = % Head Rice/% Total Rice.

[e] LSD = least significant difference.

Table 5. Results of Mississippi County Arkansas Rice Performance Trial (ARPT) during 2022 (planted 18 May; harvested 13 October).

Cultivar	Grain Type[a]	Lodging[b]	Moisture[c]	Grain Yield	Milling Yield
		(%)	(%)	(bu./ac)	(%HR/%TR)
Addi Jo	L	0	19	107	62/72
Avant	L	0	17	184	59/72
DG263L	L	61	14	162	38/69
DGL037	L	6	17	173	59/70
DGL2065	L	0	15	173	63/73
Diamond	L	0	20	186	63/72
Leland	L	0	18	164	62/73
Ozark	L	0	19	196	67/72
ProGold1	L	0	19	184	66/72
ProGold2	L	0	20	166	61/73
CLHA02	CL	0	19	186	63/72
CLL16	CL	0	20	181	56/72
CLL17	CL	29	16	148	61/71
CLL18	CL	0	19	188	63/72
CLL19	CL	0	16	181	63/72
PVL03	PL	0	17	165	58/72
RTv7231 MA	ML	0	13	168	47/71
RT 7331 MA	MLH	0	13	190	49/73
RT 7321 FP	FLH	0	14	193	35/72
RT 7421 FP	FLH	85	13	137	46/72
RT 7521 FP	FLH	68	13	132	58/71
RT 7302	LH	38	15	181	40/72
RT 7401	LH	0	13	174	41/71
RT XP753	LH	33	14	210	41/72
RT XP780	LH	0	16	224	55/71
DG353M	M	0	19	172	62/71
Jupiter	M	20	21	152	64/70
Taurus	M	0	16	160	55/70
Titan	M	19	17	164	54/70
CLM04	CM	35	19	136	65/71
Mean	–	13	17	171	56/71
$LSD_{0.05}$[e]	–	24	1	25	6/1

[a] Grain type: L = long-grain; CL = Clearfield long-grain; PL = Provisia long-grain; ML = MaxAce long-grain; MLH = MaxAce long-grain hybrid; FLH = FullPage long-grain hybrid; LH = long-grain hybrid; M = medium-grain; CM = Clearfield medium-grain.

[b] Lodging = % of plot down at harvest.

[c] Grain moisture at harvest.

[d] Milling yield = % Head Rice/% Total Rice.

[e] LSD = least significant difference.

Table 6. Results of Poinsett County Arkansas Rice Performance Trial (ARPT) during 2022 (planted 28 April; harvested 13 October).

Cultivar	Grain Type[a]	Lodging[b]	Moisture[c]	Grain Yield	Milling Yield
		(%)	(%)	(bu./ac)	(%HR/%TR)
Addi Jo	L	0	20	157	66/71
Avant	L	0	16	167	66/72
DG263L	L	0	15	184	60/70
DGL037	L	0	17	174	59/69
DGL2065	L	0	16	164	65/72
Diamond	L	0	19	179	65/72
Leland	L	0	18	170	66/73
Ozark	L	0	18	196	66/72
ProGold1	L	0	19	180	66/71
ProGold2	L	0	18	167	66/72
CLHA02	CL	0	16	161	64/71
CLL16	CL	0	21	178	63/71
CLL17	CL	0	16	154	64/71
CLL18	CL	0	20	186	64/70
CLL19	CL	0	15	183	65/71
PVL03	PL	0	16	163	66/72
RTv7231 MA	ML	0	16	187	63/71
RT 7331 MA	MLH	0	14	225	67/73
RT 7321 FP	FLH	0	15	196	63/73
RT 7421 FP	FLH	0	16	218	67/73
RT 7521 FP	FLH	0	16	228	66/72
RT 7302	LH	0	16	216	68/73
RT 7401	LH	0	13	234	66/72
RT XP753	LH	0	15	220	68/73
RT XP780	LH	0	18	225	67/72
DG353M	M	0	19	158	67/72
Jupiter	M	0	21	165	67/70
Taurus	M	0	17	173	67/72
Titan	M	0	17	203	65/71
CLM04	CM	0	18	166	68/71
Mean	–	0	17	186	65/72
$LSD_{0.05}$[e]	–	NS	2	16	1/1

[a] Grain type: L = long-grain; CL = Clearfield long-grain; PL = Provisia long-grain; ML = MaxAce long-grain; MLH = MaxAce long-grain hybrid; FLH = FullPage long-grain hybrid; LH = long-grain hybrid; M = medium-grain; CM = Clearfield medium-grain.

[b] Lodging = % of plot down at harvest.

[c] Grain moisture at harvest.

[d] Milling yield = % Head Rice/% Total Rice.

[e] LSD = least significant difference.

Table 7. Results of Clay County Arkansas Rice Performance Trial (ARPT) during 2022 (planted 28 April; harvested 14 September).

Cultivar	Grain Type[a]	Lodging[b]	Moisture[c]	Grain Yield	Milling Yield
		(%)	(%)	(bu./ac)	(%HR/%TR)
Addi Jo	L	0	21	162	61/69
Avant	L	0	16	171	64/70
DG263L	L	0	13	211	59/69
DGL037	L	0	18	192	62/69
DGL2065	L	0	16	162	65/71
Diamond	L	0	17	170	61/70
Leland	L	0	16	155	65/71
Ozark	L	0	18	190	65/71
ProGold1	L	0	17	171	64/70
ProGold2	L	0	17	154	64/71
CLHA02	CL	0	17	186	61/70
CLL16	CL	0	19	168	57/68
CLL17	CL	0	15	171	64/70
CLL18	CL	0	18	180	60/68
CLL19	CL	0	15	197	63/70
PVL03	PL	0	16	171	64/71
RTv7231 MA	ML	0	15	211	62/70
RT 7331 MA	MLH	0	13	205	64/71
RT 7321 FP	FLH	0	13	203	62/71
RT 7421 FP	FLH	0	14	194	61/70
RT 7521 FP	FLH	0	13	226	62/70
RT 7302	LH	0	16	225	65/71
RT 7401	LH	0	14	214	64/71
RT XP753	LH	0	14	194	63/71
RT XP780	LH	0	14	217	59/69
DG353M	M	0	19	161	65/70
Jupiter	M	0	23	163	63/68
Taurus	M	0	18	182	65/70
Titan	M	0	20	182	67/70
CLM04	CM	0	18	172	66/70
Mean	–	0	16	185	63/70
$LSD_{0.05}$[e]	–	NS	2	17	2/1

[a] Grain type: L = long-grain; CL = Clearfield long-grain; PL = Provisia long-grain; ML = MaxAce long-grain; MLH = MaxAce long-grain hybrid; FLH = FullPage long-grain hybrid; LH = long-grain hybrid; M = medium-grain; CM = Clearfield medium-grain.

[b] Lodging = % of plot down at harvest.

[c] Grain moisture at harvest.

[d] Milling yield = % Head Rice/% Total Rice.

[e] LSD = least significant difference.

Table 8. Results of Desha County Arkansas Rice Performance Trial (ARPT) during 2022 (planted 20 May; harvested 28 September).

Cultivar	Grain Type[a]	Lodging[b]	Moisture[c]	Grain Yield	Milling Yield
		(%)	(%)	(bu./ac)	(%HR/%TR)
Addi Jo	L	0	16	163	66/72
Avant	L	0	14	185	63/72
DG263L	L	3	13	166	60/70
DGL037	L	19	14	176	61/70
DGL2065	L	0	15	173	67/73
Diamond	L	0	14	179	60/72
Leland	L	0	17	153	68/73
Ozark	L	5	14	186	59/72
ProGold1	L	0	14	177	60/72
ProGold2	L	0	14	180	54/72
CLHA02	CL	0	16	175	63/72
CLL16	CL	6	17	169	60/72
CLL17	CL	4	13	164	63/71
CLL18	CL	19	15	185	61/71
CLL19	CL	3	13	199	63/72
PVL03	PL	0	14	173	64/73
RTv7231 MA	ML	0	13	180	53/71
RT 7331 MA	MLH	0	12	184	58/73
RT 7321 FP	FLH	0	12	160	50/72
RT 7421 FP	FLH	0	14	211	61/72
RT 7521 FP	FLH	46	13	221	62/72
RT 7302	LH	15	13	197	60/74
RT 7401	LH	0	13	200	61/73
RT XP753	LH	19	13	197	57/73
RT XP780	LH	13	15	203	60/72
DG353M	M	0	16	142	56/71
Jupiter	M	0	21	135	68/71
Taurus	M	0	14	150	58/72
Titan	M	0	15	184	54/71
CLM04	CM	0	15	169	63/72
Mean	–	5	14	178	61/72
$LSD_{0.05}$[e]	–	19	2	18	4/1

[a] Grain type: L = long-grain; CL = Clearfield long-grain; PL = Provisia long-grain; ML = MaxAce long-grain; MLH = MaxAce long-grain hybrid; FLH = FullPage long-grain hybrid; LH = long-grain hybrid; M = medium-grain; CM = Clearfield medium-grain.

[b] Lodging = % of plot down at harvest.

[c] Grain moisture at harvest.

[d] Milling yield = % Head Rice/% Total Rice.

[e] LSD = least significant difference.

Table 9. Results of Lawrence County Arkansas Rice Performance Trial (ARPT) during 2022 (planted 10 May; harvested 21 September).

Cultivar	Grain Type[a]	Lodging[b]	Moisture[c]	Grain Yield	Milling Yield
		(%)	(%)	(bu./ac)	(%HR/%TR)
Addi Jo	L	0	18	127	58/69
Avant	L	5	13	163	58/69
DG263L	L	0	13	188	55/68
DGL037	L	3	14	173	58/68
DGL2065	L	11	13	151	60/69
Diamond	L	0	13	167	57/69
Leland	L	0	15	155	62/70
Ozark	L	6	14	185	60/69
ProGold1	L	15	14	156	56/69
ProGold2	L	10	14	156	56/70
CLHA02	CL	19	13	136	49/63
CLL16	CL	5	15	167	57/69
CLL17	CL	18	13	137	59/68
CLL18	CL	0	13	179	58/68
CLL19	CL	0	12	176	58/68
PVL03	PL	0	12	147	54/68
RTv7231 MA	ML	13	13	186	53/70
RT 7331 MA	MLH	39	11	201	52/70
RT 7321 FP	FLH	30	12	159	47/70
RT 7421 FP	FLH	35	13	181	55/70
RT 7521 FP	FLH	20	12	181	53/69
RT 7302	LH	9	12	210	57/70
RT 7401	LH	3	12	200	60/72
RT XP753	LH	9	12	207	50/71
RT XP780	LH	3	14	209	54/69
DG353M	M	0	14	149	50/68
Jupiter	M	3	17	147	61/68
Taurus	M	4	14	189	59/69
Titan	M	0	14	159	50/68
CLM04	CM	40	15	146	50/69
Mean	–	10	14	170	56/69
$LSD_{0.05}$[e]	–	24	1	19	6/3

[a] Grain type: L = long-grain; CL = Clearfield long-grain; PL = Provisia long-grain; ML = MaxAce long-grain; MLH = MaxAce long-grain hybrid; FLH = FullPage long-grain hybrid; LH = long-grain hybrid; M = medium-grain; CM = Clearfield medium-grain.

[b] Lodging = % of plot down at harvest.

[c] Grain moisture at harvest.

[d] Milling yield = % Head Rice/% Total Rice.

[e] LSD = least significant difference.

Table 10. Results of Jackson County Arkansas Rice Performance Trial (ARPT) during 2022 (planted 11 May; harvested 29 September).

Cultivar	Grain Type[a]	Lodging[b]	Moisture[c]	Grain Yield	Milling Yield
		(%)	(%)	(bu./ac)	(%HR/%TR)
Addi Jo	L	0	16	154	65/72
Avant	L	0	12	147	61/71
DG263L	L	0	12	155	60/70
DGL037	L	0	15	181	62/70
DGL2065	L	0	13	154	64/72
Diamond	L	0	14	159	63/72
Leland	L	0	14	168	63/72
Ozark	L	0	13	181	65/73
ProGold1	L	0	14	158	58/71
ProGold2	L	0	13	159	50/72
CLHA02	CL	0	12	143	59/71
CLL16	CL	0	15	167	62/72
CLL17	CL	0	12	126	61/70
CLL18	CL	0	14	166	63/71
CLL19	CL	0	12	154	64/71
PVL03	PL	0	12	150	62/72
RTv7231 MA	ML	0	13	174	49/71
RT 7331 MA	MLH	0	12	169	54/73
RT 7321 FP	FLH	0	11	179	57/72
RT 7421 FP	FLH	0	12	198	60/73
RT 7521 FP	FLH	0	13	223	63/72
RT 7302	LH	0	14	205	61/73
RT 7401	LH	0	11	203	58/72
RT XP753	LH	0	12	192	52/73
RT XP780	LH	0	15	214	62/71
DG353M	M	0	15	162	63/72
Jupiter	M	0	17	142	65/70
Taurus	M	0	13	136	60/71
Titan	M	0	14	170	47/71
CLM04	CM	0	15	155	65/71
Mean	–	0	13	168	60/72
$LSD_{0.05}$[e]	–	NS	1	14	4/1

[a] Grain type: L = long-grain; CL = Clearfield long-grain; PL = Provisia long-grain; ML = MaxAce long-grain; MLH = MaxAce long-grain hybrid; FLH = FullPage long-grain hybrid; LH = long-grain hybrid; M = medium-grain; CM = Clearfield medium-grain.

[b] Lodging = % of plot down at harvest.

[c] Grain moisture at harvest.

[d] Milling yield = % Head Rice/% Total Rice.

[e] LSD = least significant difference.

Table 11. Results of Greene County Arkansas Rice Performance Trial (ARPT) during 2022 (planted 11 May; harvested 21 September).

Cultivar	Grain Type[a]	Lodging[b]	Moisture[c]	Grain Yield	Milling Yield
		(%)	(%)	(bu./ac)	(%HR/%TR)
Addi Jo	L	0	14	144	64/70
Avant	L	0	11	168	62/70
DG263L	L	6	10	181	50/68
DGL037	L	5	12	195	55/69
DGL2065	L	0	12	163	62/71
Diamond	L	0	11	163	59/70
Leland	L	0	12	156	63/71
Ozark	L	10	12	190	60/70
ProGold1	L	0	13	171	54/70
ProGold2	L	0	12	161	48/71
CLHA02	CL	0	11	164	56/70
CLL16	CL	13	12	168	55/70
CLL17	CL	24	11	136	57/69
CLL18	CL	0	12	168	59/69
CLL19	CL	1	11	167	61/70
PVL03	PL	0	11	164	56/70
RTv7231 MA	ML	53	11	152	46/70
RT 7331 MA	MLH	40	10	189	42/71
RT 7321 FP	FLH	38	11	171	41/71
RT 7421 FP	FLH	56	11	164	42/71
RT 7521 FP	FLH	60	10	161	48/70
RT 7302	LH	16	10	184	49/71
RT 7401	LH	8	11	204	45/70
RT XP753	LH	29	11	203	46/71
RT XP780	LH	9	12	187	46/70
DG353M	M	8	13	165	54/69
Jupiter	M	19	14	147	55/68
Taurus	M	15	12	149	60/70
Titan	M	19	13	168	45/69
CLM04	CM	33	13	150	58/69
Mean	–	15	12	168	53/70
$LSD_{0.05}$[e]	–	33	2	23	5/1

[a] Grain type: L = long-grain; CL = Clearfield long-grain; PL = Provisia long-grain; ML = MaxAce long-grain; MLH = MaxAce long-grain hybrid; FLH = FullPage long-grain hybrid; LH = long-grain hybrid; M = medium-grain; CM = Clearfield medium-grain.

[b] Lodging = % of plot down at harvest.

[c] Grain moisture at harvest.

[d] Milling yield = % Head Rice/% Total Rice.

[e] LSD = least significant difference.

Table 12. Results of Lonoke County Arkansas Rice Performance Trial (ARPT) during 2022 (planted 11 May; harvested 12 September).

Cultivar	Grain Type[a]	Lodging[b]	Moisture[c]	Grain Yield	Milling Yield
		(%)	(%)	(bu./ac)	(%HR/%TR)
Addi Jo	L	0	16	149	62/71
Avant	L	0	13	185	53/71
DG263L	L	0	12	222	37/69
DGL037	L	23	12	186	44/69
DGL2065	L	0	14	181	58/72
Diamond	L	0	13	183	43/70
Leland	L	0	13	173	58/71
Ozark	L	0	13	188	52/71
ProGold1	L	0	14	182	50/71
ProGold2	L	0	13	168	45/71
CLHA02	CL	0	14	183	50/70
CLL16	CL	0	16	193	47/70
CLL17	CL	0	12	179	57/70
CLL18	CL	0	13	192	48/69
CLL19	CL	0	13	185	52/70
PVL03	PL	0	13	182	56/75
RTv7231 MA	ML	0	12	195	38/70
RT 7331 MA	MLH	55	11	186	39/72
RT 7321 FP	FLH	45	12	178	33/71
RT 7421 FP	FLH	90	11	167	36/71
RT 7521 FP	FLH	68	12	187	49/70
RT 7302	LH	74	11	165	33/71
RT 7401	LH	15	11	173	32/71
RT XP753	LH	85	12	191	30/71
RT XP780	LH	33	14	196	49/69
DG353M	M	0	16	149	55/69
Jupiter	M	0	22	157	67/71
Taurus	M	0	15	153	52/72
Titan	M	0	16	200	49/68
CLM04	CM	8	18	165	66/71
Mean	–	16	14	180	48/71
$LSD_{0.05}$[e]	–	16	1	19	7/3

[a] Grain type: L = long-grain; CL = Clearfield long-grain; PL = Provisia long-grain; ML = MaxAce long-grain; MLH = MaxAce long-grain hybrid; FLH = FullPage long-grain hybrid; LH = long-grain hybrid; M = medium-grain; CM = Clearfield medium-grain.

[b] Lodging = % of plot down at harvest.

[c] Grain moisture at harvest.

[d] Milling yield = % Head Rice/% Total Rice.

[e] LSD = least significant difference.

Grain Yield Response of Seven New Rice Cultivars to Nitrogen Fertilization

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Abstract

The purposes of the cultivar x nitrogen (N) studies are the observation, collection, and analysis of the growth and yield response of new rice (*Oryza sativa* L.) cultivars to N fertilization. The collection of this data is used to determine the optimal N fertilizer rates across the range of soils and environments in which rice is grown in Arkansas. Eight cultivars were studied in 2022: Addi Jo, Avant, CLL18, DG263L, Diamond, Ozark, PVL03, and Taurus at 4 locations: the University of Arkansas System Division of Agriculture's Northeast Research and Extension Center (NEREC), the Northeast Rice Research and Extension Center (NERREC) the Pine Tree Research Station (PTRS), and the Rice Research and Extension Center (RREC). Seed treatment and seeding rates followed current recommendations and production practices. The grain yields were fair to good for all cultivars studied at the 4 locations in 2021 with little to no lodging reported for all cultivars across all locations. The 2022 season was the first year the cultivars Addi Jo, Avant, CLL18, Ozark, and Taurus were included and the second year of inclusion for the cultivar PVL03; therefore, there is insufficient data to make a N rate recommendation at this time, and hence the response to N reported here can serve as a guide while more data is collected in subsequent years. Three years of results for DG263L provide evidence that this cultivar should have excellent yields with minimal to no lodging if 135 pounds (lb) of N/ac is applied in a 2-way split of 90 lb N/ac at the preflood timing followed by 45 lb N/ac at midseason when grown on silt loam soils and 165 lb N/ac in a 2-way split of 120 lb N/ac at the preflood timing followed by 45 lb N/ac applied at midseason when grown on clay soils.

Introduction

The objectives of the cultivar x nitrogen (N) fertilizer rate trials are to record and analyze the grain yield performance of new rice cultivars over a range of fertilizer rates on a representative clay and three silt loam soils as well as diverse growing environments existing in Arkansas. The goal is to determine the appropriate N fertilizer rates conducive to maximizing grain yields, maximizing returns per unit of fertilizer, and providing sound research-based baseline N management data for Arkansas rice producers. Selections of promising new cultivars from breeding programs in Arkansas, Louisiana, Mississippi, and Texas as well as from private industry are evaluated in these trials. A total of 8 cultivars were included in 2022 at 4 locations.

Procedures

The cultivar x N fertilizer rate studies were conducted at the following University of Arkansas System Division of Agriculture (UADA) research locations: the Northeast Research and Extension Center (NEREC) near Keiser, Ark., on a Sharkey Clay (Vertic Haplaquepts) soil; the Northeast Rice Research and Extension Center (NERREC) near Harrisburg, Ark., for the first time, on a Henry silt loam (Typic Fragiaqualfs), the Pine Tree Research Station (PTRS) near Colt, Ark., on a Calloway silt loam (Glossaquic Fragiudalfs) soil; and the Rice Research and Extension Center (RREC) near Stuttgart, Ark., on a Dewitt silt loam (Typic Albaqualfs) soil. The cultivars studied were Addi Jo, Avant, CLL18, DGL263, Ozark, Diamond, PVL03 and Taurus. The method employed for data analysis for all locations and each cultivar is a randomized complete block design with 4 replications. All seed of each cultivar was treated with fungicides and insecticide following current recommendations and practices in addition to an application of a zinc (Zn) seed treatment. All experimental plots were direct-seeded in eight rows at 7.5-in. spacing and 18 ft in length at a rate of 33 seed/ft^2. A single preflood N fertilizer application (SPF) was employed for all cultivars across all locations as urea treated with a urease inhibitor (NBPT) onto a dry soil surface at the 4- to 5-leaf growth stage. The preflood N rates were: 0, 60, 90, 120, 150, 180, and 210 lb N/ac. The locations with silt loam soils (PTRS, NERREC, and RREC) received the 0 to 180 lb N/ac rate structure and the study on the clay soil (NEREC) implemented the 0 to 210 lb of N/ac rate structure with the omission of the 60 lb N/ac rate. Pertinent agronomic dates and practices for each location are reported in Table 1. The permanent flood was established within 24–48 hrs of the preflood N application and maintained until maturity of the

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rice crop. At maturity, the flood was released and approximately 2 weeks later the 4 center rows of each plot were harvested, and grain moisture content, yield and lodging were recorded. Yields were calculated as bushels per acre (bu./ac) and adjusted to 12% moisture, with a bushel of rice base weight of 45 lb. Statistical analysis was conducted using PROC GLIMMIX, SAS v. 9.4 (SAS Institute, Inc. Cary, N.C.) with means separation using T grouping for least-square means at an $\alpha = 0.05$.

Results and Discussion

In 2008, a single preflood N application was adopted in all cultivar x N studies in response to the rising cost of N fertilizer and the preference of medium to short stature, semi-dwarf, and stiff straw plant types currently grown. These cultivars typically reach maximal yield potential when less N is applied in a SPF application in comparison with the traditional 2-way split application. Typically, cultivars receiving a SPF application require 20 to 30 lb N/ac less than when N is applied in a 2-way split application where the second application is made between beginning internode elongation and the 0.5-in. internode elongation growth stages. Hence, if 150 lb N/ac is recommended for a 2-way application, then 120 to 130 lb N/ac should maximize yield potential using a single preflood application only if certain critical conditions are met. These conditions include: 1) that the field can be flooded timely, 2) the urea has been treated with the urease inhibitor NBPT or ammonium sulfate is used instead as a source of N, unless the field can be flooded in 2 days or less for silt loam soils and 7 days or less for clay soils, and 3) a flood of 2 to 4 inches is maintained for at least 3 weeks after flood establishment (Norman et al., 2003; Roberts et al., 2018).

Overall, the yields for the 2022 cultivar x N rate trials were fair to good for most of the 8 cultivars included. Maximal yields ranged from 99 to 215 bu./ac for the NEREC location, 166 to 218 bu./ac at the NERREC location, 149 to 207 bu./ac for PTRS, and 178 to 211 bu./ac for the RREC location. There were minimal lodging scores reported, with a few plots damaged by wildlife at the PTRS location. In 2022, planting dates in late March at RREC, and late April at NERREC yielded higher compared to planting dates in early and late May for PTRS and NEREC, respectively (Table 1). The effect of planting date on rice yields has been observed previously by Clayton et al. (2021, 2022). The lower yields for the PTRS and NEREC locations compared to the information gathered in 2021 may be attributed to the later planting date in 2022 (Castaneda-Gonzalez et al., 2022), whereas all locations in 2021 were seeded in early to mid-April. Two different responses to increasing rates of N fertilizer are observed in the cultivar x N trials, a simple linear trend where yields continued to increase as N rate increased or quadratic (logarithmic trend) where the grain yield reached a vertex, possibly a plateau followed by decreasing yields. The results indicate that either response is independent of cultivar and greatly influenced by biotic and abiotic factors (environment).

The cultivar Addi Jo achieved a maximal yield of 178 bu./ac at the RREC location followed by 166 bu./ac at NERREC, 158 bu./ac at the PTRS, and 99 bu./ac at NEREC when N rates of 150, 120, 150, and 180 lb N/ac were applied, respectively (Table 2). The data suggests that this cultivar's yield tends to plateau between 150 lb N/ac for clay soils and 120–180 lb N/ac for silt loam soils. The lowest preflood N rate in a single preflood application that produced a statistically similar yield to the maximal yield for a given location was identified as 90 lb N/ac for the clay soil and 150 lb N/ac for the 3 silt loam soils. The response to N fertilizer for this cultivar was quadratic except for the PTRS location where the response was linear with a maximal grain yield of 158 bu./ac with the highest N rate of 180 lb N/ac. Maximal yields for Addi Jo were erratic across locations. 2022 is the first year of inclusion in the V x N trials for Addi Jo and the grain yields recorded were some of the lowest at all locations.

The rice cultivar Avant (Table 3), included for the first time in 2022, showed favorable grain yield increase in comparison with Addi Jo and more like Diamond with maximal yields of 174 bu./ac at 120 lb N/ac at the NEREC location, 178 bu./ac and 182 bu./ac with a rate of 180 lb N/ac for the NERREC and PTRS locations, and 167 bu./ac with 150 lb N/ac for RREC. Maximal grain yield was stable across locations. The lowest fertilizer rate producing a grain yield non-statistically different from the maximal was 60 lb N/ac with 170 bu./ac at NERREC, and 90 lb N/ac with 153, 175, and 165 bu./ac at NEREC, PTRS, and RREC, respectively. These results, while preliminary, indicate that the cultivar Avant has minimal response to N rates above 90 lb N/ac. Further testing will be required to determine the response of Avant to different N fertilizer rates.

For the cultivar CLL18 (Table 4), this is the first year of inclusion. Peak yields of 165, 199, 178, and 204 bu./ac were recorded at the 150, 150, 180, and 180 lb N/ac preflood N rates for NEREC, NERREC, PTRS, and RREC, respectively. The response to N fertilization appeared to be quadratic for the NEREC and NERREC and linear for the PTRS and RREC locations. The lowest N rate producing a grain yield that was statistically similar to that of the maximum yield was 90 lb N/ac for NEREC and RREC with 144 and 187 bu./ac, respectively, and 120 lb N/ac with 168 and 191 bu./ac for PTRS and NERREC, respectively. The yields were not consistent across locations but being the first year of inclusion and promising yields, further testing of this cultivar would be advised.

The overall yields of the cultivar DG263L (Table 5), included for the third time in the cultivar x N studies, were among the highest of all cultivars tested in the 2020 and 2021 trials, (Castaneda-Gonzalez et al. 2021, 2022). DG263L was one of the highest performers in 2022 as well, displaying stability across locations and years. The peak yields recorded for this cultivar were 210, 217, 190, and 203 bu./ac at N rates of 90, 120, 180, and 90 lb N/ac for the NEREC, NERREC, PTRS, and RREC, respectively. The response to N rate was linear at PTRS and quadratic for NEREC, NERREC, and RREC where levels of N above 90 to 120 lb N/ac resulted in lower yields. The grain yields were stable across locations. The results of 3 seasons provide evidence to assert that the cultivar DG263L should yield 180 to 200 bu./ac when a rate of 90 to 120 lb N/ac in a SPF application for silt loams or a single application of 90–150 lb N/ac for a clay soil, or its equivalent for a split application, is provided.

The cultivar Diamond (Table 6) is included as a check variety for its good performance across soil types, environment, and multi-year results. It serves as a baseline for the understanding of the performance of newer varieties included in the cultivar x N studies. In 2022, maximal yields for Diamond were 167 bu./ac (120 lb N/

ac), 188 bu./ac (120 lb N/ac), 176 bu./ac (180 lb N/ac), and 209 bu./ac (180 lb N/ac) for NEREC, NERREC, PTRS, and RREC, respectively. The yield response to N rate was linear for PTRS and RREC, and quadratic for NEREC and NERREC with minimum N rates to achieve maximal yield not significantly different to the peak yield being 90 lb N/ac with 151 bu./ac and 170 bu./ac at NEREC and NERREC, 150 lb N/ac (174 bu./ac) at PTRS, and 120 lb N/ac (209 bu./ac) at RREC. Diamond performance was less consistent than in previous years across sites and N rates (Castaneda-Gonzalez et al. 2020, 2021). It is against this variety that the results gathered in 2022 must be compared to make assessments.

Ozark was added for the first time to the cultivar x N trials and exhibited consistent yield across locations and a peak grain yield of 185 bu./ac (120 lb N/ac) at NEREC, 205 bu./ac (120 lb N/ac) at NERREC, 207 bu./ac (180 lb N/ac) at PTRS and 206 bu./ac (180 lb N/ac) at RREC (Table 7). The response of Ozark was linear for PTRS and RREC and quadratic for NEREC and NERREC where N rates exceeding 120 lb N/ac resulted in lower yields as the N rates increased. The lowest yield-maximizing N rates were 60 lb N/ac for the NERREC and RREC locations, 90 lb N/ac for the NEREC, and 120 lb/ac for PTRS with 190, 191, 173, and 186 bu./ac. Additional data needs to be collected for Ozark to make an accurate assessment of this cultivar and its optimal N fertilization strategy.

The 2022 season is the second year that PVL03 was included in the cultivar x N test. PVL03 maximal yields were 153 bu./ac (180 lb N/ac) at NEREC, 176 bu./ac (90 lb N/ac) at NERREC, 149 bu./ac (150 lb N/ac) at PTRS, and 180 bu./ac (180 lb N/ac) for RREC (Table 8). The yield response was quadratic for all locations except RREC with a linear response. In 2021 a linear response was observed only at PTRS with a quadratic response for NEREC and RREC. The lowest N rate with a grain yield not significantly different to the peak yield was 90 lb N/ac with 138 and 170 bu./ac at NEREC and RREC, respectively; 150 lb N/ac with 149 bu./ac at PTRS; and 90 lb N/ac with 170 bu./ac at RREC. More information is required on this cultivar to make a proper assessment.

Another promising cultivar included for the first time in the 2022 season cultivar x N trials is Taurus. Yields for this cultivar ranged from fair to excellent at the 4 locations with the overall highest yields reported at the NERREC location. Peak yields for Taurus were 215 bu./ac (150 lb N/ac), 218 bu./ac (180 lb N/ac), 179 bu./ac (180 lb N/ac), and 211 bu./ac (180 lb N/ac) at the NEREC, NERREC, PTRS, and RREC locations, respectively (Table 9). Taurus displayed consistent grain yields across locations. The grain yield response to N fertilization rates was quadratic for NEREC and linear for all other locations. The lowest N rate resulting in yields not statistically different to the peak yields were 120 lb N/ac with 197, 209, and 169 bu./ac for NEREC, NERREC, and PTRS, respectively, and 90 lb N/ac with 196 bu./ac for RREC. Additional data will be required to properly assess the grain yield response to N fertilization of the cultivar Taurus.

Practical Applications

The cultivar x N fertilizer rate trials are a key component of assessing new rice cultivars and developing baseline preflood N and season total N fertilizer requirements to maximize grain yield and productivity. The primary objective is to record and analyze the grain yield performance of new rice cultivars over a range of fertilizer rates on representative soils as well as diverse growing environments in the Arkansas rice growing region. Therefore, the result of these trials can be utilized to provide the proper N fertilizer rates to achieve maximal grain yields and best returns per lb of N applied when grown commercially in the Arkansas rice growing region. Within the cultivar x N trials we intend to restrict effects other than fertilizer rate; the effect of variables not subject to manipulation like the weather and accidental damage not caused by our management underlines the need of multi-year testing. The 2022 growing season was a year of opportunity to test sustainability of yields under varied conditions. The differences observed in the 2022 data and previous research regarding the nature of the responses and the grain yield as a result of particular N rate emphasized the influence of the environmental effect on these tests and provided further evidence of the need for multi-year testing.

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Table 1. Pertinent agronomic information for the University of Arkansas System Division of Agriculture's Northeast Research and Extension Center (NEREC), Northeast Rice Research and Extension Center (NERREC), Pine Tree Research Station (PTRS), and the Rice Research and Extension Center (RREC) during 2022.

Practices	NEREC	NERREC	PTRS	RREC
Planting Dates	18 May 2022	29 April 2022	9 May 2022	29 March 2022
Herbicide Spray Dates and Spray Procedures	27 May 2022 1.5 pt Command Aerial broadcast	unrecorded	11 May 2022 10 oz VoPak (Command)+22 oz Facet L + 4 oz League+ 32 oz Makaze (Glyphosate) Broadcast	1 April 2022 4 oz League + 10 oz Command Broadcast
Flush Dates	-----	-----	-----	-----
Emergence Dates	25 May 2022	6 May 2022	15 May 2022	13 April 13 2022
Herbicide Spray Dates and Spray Procedures	15 June 2022 43 oz Facet+ 0.75 oz Permit Plus 4 qts Propanil Broadcast	Unrecorded	24 May 2022 2 pt Stealth + 21 oz Facet +15 oz Ricestar HT Broadcast	11 May 2022 21 oz Facet L + 3 qts Stam + 2 pts Prowl H2O Broadcast
Herbicide Spray Dates and Spray Procedures	9 July 2022 22 oz Facet + 15 oz Clincher Aerial Broadcast	Unrecorded	-----	31 May 2022 # qts Stam + 2 pts Bolero + 1 oz Permit Plus Broadcast
Herbicide Spray Dates and Spray Procedures	22 July 2022 10 oz Clincher + 1 qt COC† Aerial Broadcast	Unrecorded	-----	21 June 2022 15 oz Clincher + 1 qt COC Broadcast
Herbicide Spray Dates and Spray Procedures	-----	-----	12 oz Command + 23 oz Facet L. Levees only Broadcast	14 July 2022 15 oz Clincher + 20 oz COC Broadcast
Preflood N dates	22 June 2022	16 June 2022	16 June 2022	1 June 2022
Flood Dates	24 June 2022	17 June 2022	17 June 2022	2 June 2022
Insecticide Spray Dates and Spray Procedures	None	None	None	None
Drain Dates	16 September 2022	Unrecorded	Unrecorded	30 August 2022
Harvest dates	13 October 2022	21 September 2022	27 September 2022	19 September 2022

† COC = crop oil concentrate.

Table 2. Influence of nitrogen (N) fertilizer rate on the grain yield of Addi Jo rice at four locations during 2022.

	Locations			
N Fertilizer Rates	**NEREC**†	**NERREC**	**PTRS**	**RREC**
(lb N/ac)	---	**(bu./ac)**	---	---
0	74.4 b‡	117.5 b	78.5 d	122.1 d
60	---	155.4 a	114.2 c	142.7 c
90	87.4 a	161.0 a	120.9 c	152.5 bc
120	90.8 a	165.7 a	138.2 b	163.4 ab
150	98.9 a	164.1 a	146.3 ab	178.1 a
180	98.1 a	159.6 a	157.9 a	172.3 a
210	95.8 a	---	---	---

† NEREC = Northeast Research and Extension Center, Keiser, Ark.; NERREC = Northeast Rice Research and Extension Center, Harrisburg, Ark.; PTRS = Pine Tree Research Station, Colt, Ark.; RREC = Rice Research and Extension Center, Stuttgart, Ark.

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

Table 3. Influence of nitrogen (N) fertilizer rate on the grain yield of Avant rice at four locations during 2022.

	Locations			
N Fertilizer Rates	**NEREC**†	**NERREC**	**PTRS**	**RREC**
(lb N/ac)	---	**(bu./ac)**	---	---
0	97.9 b‡	145.7 b	84.6 c	100.3 c
60	---	170.2 a	158.6 b	147.4 b
90	152.8 a	176.4 a	174.5 a	165.3 ab
120	173.5 a	170.7 a	181.8 a	160.2 ab
150	171.0 a	172.8 a	181.5 a	167.4 a
180	168.5 a	178.1 a	182.2 a	150.3 ab
210	172.7 a	---	---	---

† NEREC = Northeast Research and Extension Center, Keiser, Ark.; NERREC = Northeast Rice Research and Extension Center, Harrisburg, Ark.; PTRS = Pine Tree Research Station, Colt, Ark.; RREC = Rice Research and Extension Center, Stuttgart, Ark.

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

Table 4. Influence of nitrogen (N) fertilizer rate on the grain yield of CLL18 rice at four locations during 2022.

	Locations			
N Fertilizer Rates	**NEREC**†	**NERREC**	**PTRS**	**RREC**
(lb N/ac)	---	**(bu./ac)**	---	---
0	89.7 b‡	141.9 d	82.7 d	150.3 c
60	---	174.2 c	128.3 c	184.5 b
90	144.1 a	183.7 bc	154.8 b	187.8 ab
120	162.5 a	191.4 ab	167.8 ab	199.4 ab
150	165.0 a	199.4 a	176.6 a	198.4 ab
180	162.7 a	193.5 ab	178.2 a	203.6 ab
210	146.4 a	---	---	---

† NEREC = Northeast Research and Extension Center, Keiser, Ark.; NERREC = Northeast Rice Research and Extension Center, Harrisburg, Ark.; PTRS = Pine Tree Research Station, Colt, Ark.; RREC = Rice Research and Extension Center, Stuttgart, Ark.

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

Table 5. Influence of nitrogen (N) fertilizer rate on the grain yield of DG263L rice at four locations during 2022.

	Locations			
N Fertilizer Rates	**NEREC**[†]	**NERREC**	**PTRS**	**RREC**
(lb N/ac)	---------------------	--------(bu./ac)--------	---------------------	---------------------
0	168.5 b[‡]	167.5 c	87.8 c	162.1 b
60	---	211.9 ab	145.7 b	189.5 a
90	209.6 a	207.9 b	167.0 a	202.9 a
120	206.1 a	217.0 a	189.2 a	196.6 a
150	207.0 a	207.5 b	179.2 a	190.5 a
180	196.3 a	208.5 ab	189.8 a	200.5 a
210	196.6 a	---	---	---

[†] NEREC = Northeast Research and Extension Center, Keiser, Ark.; NERREC = Northeast Rice Research and Extension Center, Harrisburg, Ark.; PTRS = Pine Tree Research Station, Colt, Ark.; RREC = Rice Research and Extension Center, Stuttgart, Ark.

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

Table 6. Influence of nitrogen (N) fertilizer rate on the grain yield of Diamond rice at four locations during 2022.

	Locations			
N Fertilizer Rates	**NEREC**[†]	**NERREC**	**PTRS**	**RREC**
(lb N/ac)	---------------------	--------(bu./ac)--------	---------------------	---------------------
0	108.9 c[‡]	146.4 c	70.3 e	142.2 d
60	---	155.0 c	124.0 d	180.2 c
90	151.4 ab	170.7 abc	143.8 c	190.3 bc
120	167.4 ab	188.2 a	153.3 bc	201.4 ab
150	162.3 ab	180.3 ab	173.9 ab	202.0 ab
180	164.7 ab	174.1 abc	176.7 a	209.2 a
210	142.4 a	---	---	---

[†] NEREC = Northeast Research and Extension Center, Keiser, Ark.; NERREC = Northeast Rice Research and Extension Center, Harrisburg, Ark.; PTRS = Pine Tree Research Station, Colt, Ark.; RREC = Rice Research and Extension Center, Stuttgart, Ark.

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

Table 7. Influence of nitrogen (N) fertilizer rate on the grain yield of Ozark rice at four locations during 2022.

	Locations			
N Fertilizer Rates	**NEREC**[†]	**NERREC**	**PTRS**	**RREC**
(lb N/ac)	---------------------	--------(bu./ac)--------	---------------------	---------------------
0	121.5 b[‡]	151.1 b	92.6 d	127.6 c
60	---	190.4 a	159.5 c	191.2 ab
90	173.3 a	205.0 a	173.4 bc	191.9 ab
120	184.7 a	205.0 a	185.7 ab	182.4 b
150	183.4 a	200.4 a	188.1 ab	197.4 ab
180	177.4 a	198.6 a	207.0 a	205.5 a
210	165.6 a	---	---	---

[†] NEREC = Northeast Research and Extension Center, Keiser, Ark.; NERREC = Northeast Rice Research and Extension Center, Harrisburg, Ark.; PTRS = Pine Tree Research Station, Colt, Ark.; RREC = Rice Research and Extension Center, Stuttgart, Ark.

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

Table 8. Influence of nitrogen (N) fertilizer rate on the grain yield of PVL03 rice at four locations during 2022.

	Locations			
N Fertilizer Rates	NEREC†	NERREC	PTRS	RREC
(lb N/ac)	----------------------	(bu./ac)	----------------------	
0	92.4 b‡	132.4 b	72.2 c	102.8 c
60	---	171.0 a	119.0 b	153.6 b
90	138.0 a	175.9 a	129.8 b	170.0 ab
120	149.1 a	173.8 a	147.5 b	176.8 ab
150	147.0 a	171.5 a	148.9 a	177.7 ab
180	152.7 a	163.8 a	146.9 a	180.0 a
210	150.4 a	---	---	---

† NEREC = Northeast Research and Extension Center, Keiser, Ark.; NERREC = Northeast Rice Research and Extension Center, Harrisburg, Ark.; PTRS = Pine Tree Research Station, Colt, Ark.; RREC = Rice Research and Extension Center, Stuttgart, Ark.

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

Table 9. Influence of nitrogen (N) fertilizer rate on the grain yield of Taurus rice at four locations during 2022.

	Locations			
N Fertilizer Rates	NEREC†	NERREC	PTRS	RREC
(lb N/ac)	----------------------	(bu./ac)	----------------------	
0	138.0 c‡	151.0 d	78.8 d	164.1 c
60	---	192.1 c	119.2 c	182.0 bc
90	184.5 b	201.6 b	132.7 b	195.9 ab
120	197.1 ab	209.3 ab	168.7 a	207.6 a
150	214.7 a	214.7 a	170.7 a	209.9 a
180	210.3 a	217.9 a	178.9 a	211.15 a
210	200.0 ab	---	---	---

† NEREC = Northeast Research and Extension Center, Keiser, Ark.; NERREC = Northeast Rice Research and Extension Center, Harrisburg, Ark.; PTRS = Pine Tree Research Station, Colt, Ark.; RREC = Rice Research and Extension Center, Stuttgart, Ark.

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

2022 Degree-Day 50 (DD50) Thermal Unit Thresholds for New Rice Cultivars and Seeding Date Studies

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Abstract

The Degree-Day 50 (DD50) computer program is one of the most successful management aids developed by the University of Arkansas System Division of Agriculture. This program predicts critical growth stages that assist in increasing the effectiveness of crop management operations. In order to maintain its relevance, the computer program must be updated continually as new rice cultivars become available to growers. In order to accomplish this goal, studies are conducted in a controlled research environment where developmental data and DD50 thermal unit thresholds for current and new cultivars are determined. Throughout the 2022 season, DD50 thermal unit accumulation, developmental data, and the effect of seeding date (SD) on grain and milling yield potential for 21 cultivars were evaluated over 6 SDs under a dry-seeded, delayed-flood management system commonly used in southern U.S. rice production. Significant differences in grain yield were observed for all 21 cultivars at each location.

Introduction

The Degree-Day 50 (DD50) is an outgrowth of the growing degree-day concept where daily high and low air temperatures are used to determine a day's thermal quality for plant growth. Conceived in the 1970s as a tool to time midseason nitrogen (N) applications, the DD50 computer program has grown into a management aid that provides predicted dates for timing 26 key management decisions including fertilization, pesticide applications, permanent flood establishment, times for scouting insect and disease, predicted draining date and suggested harvest time (Hardke et al., 2018).

Beginning at emergence, the DD50 (days with a minimum average temperature of at least one degree above 50 °F) generates a predicted, cultivar-specific, rice plant development file based in the accumulation of DD50 units calculated using the formula: DD50 = (Daily Maximum + Daily Minimum/2)-50, considering that Maximum temperature = 94 °F if maximum temperature is >94 °F, and Minimum temperature = 70 °F if minimum temperature is >70 °F. The growth stages predicted are beginning optimum tillering, beginning internode (BIE), half-inch internode elongation (0.5-inch IE), 50% heading, drain date, and 20% grain moisture (Hardke et al., 2018). The initial file is created by calculating thermal unit accumulation using a 30-year average weather data set collected by the National Weather Service weather station closest to rice producer's location in Arkansas. As the season progresses, the program is updated with the current year's weather data on a daily basis which improves accuracy.

The data used to predict plant development for a specific cultivar are generated in yearly studies where promising experimental lines and newly released conventional and hybrid rice cultivars are evaluated in 4 to 6 seeding dates (SDs) per season within the recommended range of rice SDs for Arkansas. Once a new cultivar is released, the information obtained in these studies is utilized to provide threshold DD50 thermal units to the DD50 computer program that enables the prediction of dates of plant developmental stage occurrences and predictions of suggested dates when particular management practices could be performed. Therefore, the objectives of this study were to develop a DD50 thermal accumulation database for promising new cultivars, verification and refinement of the existing database of current cultivars, assessment of the effect of SD on DD50 thermal unit accumulation, and also effects of SD on grain and milling yields of a particular cultivar for the identification of optimal SDs.

Procedures

The 2022 DD50 study was conducted at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC) near Stuttgart, Ark. on a DeWitt silt loam soil, and the Northeast Rice Research and Extension Center (NERREC) near Harrisburg, Ark. on a Calloway silt loam soil. Thirteen pure-line cultivars (Avant, Addi Jo, ARoma22, CLL16, CLL17, CLL18, CLM04, DG263L, Diamond, Ozark, PVL03, Taurus, and Titan) were dry-seeded at a rate of 33 seed/ft^2 in plots 8 rows wide (7.5-in. spacing) and 17.5 ft long, and 6 hybrids (RT XP753, RT 7302, RT 7401, RT 7321 FP, RT 7421 FP, RT 7521 FP, RT 7331 MA, and RTv7231 MA) were seeded into plots of the same dimensions using the reduced seeding rate for hybrids (11 seed/ft^2). The SDs for 2021 were 21 March, 4 April, 21 April, 30 April, 16 May, and 1 June for the RREC, and 21 March, 4 April, 19 April, 28 April, 17 May, and 1 June for the NERREC. Standard cultural practices were followed according to University of Arkansas System Division of Agriculture recommendations. A single preflood

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nitrogen (N) application of 130 lb N/ac was applied to all plots at RREC and NERREC at the 4- to 5-leaf growth stage and flooded within 2 days of application. Data collected include maximum and minimum temperatures, date of seedling emergence, and the number of days and DD50 units required to reach 50% heading. The number of days and DD50 thermal units required to reach 0.5-inch internode elongation (IE) was also collected for April 4 and April 30 at the RREC location. At maturity, the 4 center rows in each plot were harvested, weight of grain and moisture content were recorded, and a subsample of harvested grain was taken for milling purposes on all SDs. The grain yield was adjusted to 12% moisture and reported on a bushel per acre (bu./ac) basis. The dry rice was milled to obtain data on percent of head rice and percent of total white rice (%HR/%TR). Study design was a randomized complete block with 4 replications for each SD. Statistical analysis was conducted using PROC GLM, SAS v. 9.4 (SAS Institute, Inc. Cary, N.C.) with means separation using Fisher's least significant difference test ($P = 0.05$).

Results and Discussion

The amount of time between seeding and emergence ranged from 7-28 days at the NERREC and 6-20 days at the RREC, directly affecting the required days from seeding to flooding (Tables 1 and 2). In general, SD studies report a decrease in days between seeding and emergence as the SD is delayed. The 2022 study followed this general trend of decreasing days from seeding to emergence as SD was delayed from late March to late May. The time from seeding to establishment of permanent flood followed the same trend as the SD was delayed, ranging from 73 days for the 21 March to 28 for the 1 June SDs at NERREC and 65 days for the 21 March to 28 for the 1 June SDs at RREC. The times from emergence to flooding also follow the general trend of decreasing days with later SDs.

A decreasing trend in days and thermal units was observed to reach 0.5-in IE from emergence as SD was delayed at RREC (Table 3) as was the case for 2020 and 2021 (Clayton et al., 2021, 2022). The cultivars DG263L, PVL03, and RTv7231MA required the fewest days and DD50 units to reach 0.5-in IE with 50, 51, and 51 days, respectively and 1368, 1398, and 1385 DD50 units, respectively. Addi Jo, CLL18, Ozark, and Taurus required the most days and DD50 units to reach 0.5-in IE with 67 days, and 1652, 1644, 1644, and 1652 DD50 units, respectively. The average days to 0.5-in IE across planting dates was 60 and the average DD50 units across planting dates was 1546.

The average days needed to reach the developmental stage known as 50% heading from the time of emergence across SDs and cultivars was 84 days at the RREC and 87 days at the NERREC (Tables 4 and 5). The average time for cultivars to reach 50% heading ranged from 75 to 95 days at the RREC and from 80 to 101 days at the NERREC across SDs. For individual cultivars, the time required to reach 50% heading ranged from 100 days for CLL16 to 68 days for RTv7231 MA at the RREC. For the NERREC, the days to 50% heading ranged from 106 days for CLL18 to 73 days for DG263L. For 2022, the thermal unit accumulation from emergence to 50% heading averaged 2319 DD50 units at the RREC and 2385 DD50 units at the NERREC. The individual cultivar thermal unit accumulation from emergence to 50% heading ranged from 2145 DD50 units for DG263L to 2588 DD50 units for Addi Jo at the NERREC. For the RREC, thermal unit accumulation from emergence to 50% heading ranged from 2074 DD50 units for DG263L and RTv7231 MA to 2606 DD50 units for Addi Jo. The lowest average thermal unit accumulation was the 16 May planting at the RREC and 5 April at the NERREC.

The average grain yield for 2022 at the RREC was 178 bu./ac and 187 bu./ac at the NERREC across SDs (Tables 6 and 7). The highest average grain yield across all cultivars was the 20 April SD at the NERREC and the 20 April SD at the RREC. On average, DG263L was the highest-yielding variety and the hybrid RT 7302 yielded the highest at RREC. On average, Ozark was the highest-yielding variety and RT 7302 was the highest-yielding hybrid at NERREC.

The milling yields for 2022, averaged across SDs and cultivars, was 54/68 (%HR/%TR) at the RREC and 62/70 at the NERREC (Tables 8 and 9). The milling yields were higher for all the SDs at the NERREC than the RREC.

Practical Applications

The data obtained during 2022 will be used to improve the DD50 thermal unit threshold for new cultivars and hybrids being grown. The grain and milling yield data contribute to the database of information used by University personnel to help producers make decisions in regard to rice cultivar selection, in particular for early- and late-seeding situations.

Acknowledgments

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Table 1. General seeding, seedling emergence, and flooding date information for the DD50 seeding date study in 2022 at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center near Stuttgart, Ark.

	Seeding Date					
	21 March	**4 April**	**19 April**	**30 April**	**16 May**	**1 June**
Emergence date	10 April	18 April	1 May	7 May	22 May	8 June
Flood date	25 May	25 May	7 June	14 June	17 June	29 June
Days from seeding to emergence	20	14	12	7	6	7
Days from seeding to flooding	45	37	37	38	26	21
Days from emergence to flooding	65	51	49	45	32	28

Table 2. General seeding, seedling emergence, and flooding date information for the DD50 seeding date study in 2022 at the University of Arkansas System Division of Agriculture's Northeast Rice Research and Extension Center near Harrisburg, Ark.

	Seeding Date					
	21 March	**4 April**	**19 April**	**28 April**	**17 May**	**1 June**
Emergence date	18 April	25 April	2 May	6 May	24 May	8 June
Flood date	2 June	2 June	10 June	17 June	23 June	29 June
Days from seeding to emergence	28	21	13	8	7	7
Days from seeding to flooding	45	38	39	42	30	21
Days from emergence to flooding	73	59	52	50	37	28

Table 3. Influence of seeding date on DD50 accumulations and days from emergence to 0.5-inch internode elongation of selected rice cultivars in studies conducted at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center during 2022.

	Seeding Date					
	4 April		30 April		Average	
Cultivar	**days**	**DD50 units**	**days**	**DD50 units**	**days**	**DD50 units**
Addi Jo	67	1652	61	1697	64	1671
ARoma22	72	1772	62	1732	67	1752
Avant	61	1453	53	1446	57	1449
CLL18	67	1644	58	1604	62	1624
DG263L	58	1361	50	1368	54	1364
Diamond	66	1620	57	1589	62	1605
Ozark	67	1644	59	1652	63	1648
PVL03	61	1445	51	1398	56	1421
RT 7331 MA	65	1572	54	1478	59	1525
RT 7401	65	1580	55	1518	61	1553
RT 7421 FP	64	1532	53	1446	58	1489
RT 7302	64	1532	53	1454	58	1493
RTv7231 MA	60	1422	51	1385	55	1403
Taurus	67	1652	60	1676	64	1664
Mean	64	1563	55	1528	60	1546
$LSD_{(\alpha=0.05)}$[a]	1.44	45.73	1.11	34.92	5.04	38.06

[a] LSD = least significant difference.

Table 4. Influence of seeding date on DD50 accumulations and days from emergence to 50% heading of selected rice cultivars in studies conducted at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center during 2022.

	Seeding Date													
	21 March		4 April		19 April		30 April		16 May		1 June		Average	
Cultivar	days	DD50 units	days	DD50 units	days	DD50 units	days	DD50 units	days	DD50 units	days	DD50 units	days	DD50 units
Addi Jo	98	2350	97	2584	93	2590	90	2606	88	2604	85	2578	92	2551
ARoma22	96	2294	93	2456	87	2393	85	2453	77	2285	76	2311	86	2365
Avant	93	2175	88	2282	85	2353	81	2341	73	2155	72	2197	82	2253
CLL16	100	2414	96	2536	89	2481	88	2553	77	2292	79	2382	89	2445
CLL17	96	2270	91	2376	85	2337	82	2364	78	2308	75	2278	85	2324
CLL18	96	2286	95	2512	89	2465	84	2409	78	2322	78	2347	87	2390
CLM04	97	2326	93	2432	86	2385	85	2462	81	2390	81	2443	87	2404
DG263L	95	2238	88	2274	82	2258	81	2318	70	2074	69	2103	81	2211
Diamond	95	2262	93	2432	87	2401	84	2422	78	2308	75	2265	85	2348
Ozark	97	2318	92	2424	86	2385	83	2395	77	2286	74	2259	85	2344
PVL03	97	2326	93	2448	88	2441	83	2393	78	2322	78	2360	86	2382
RT 7321 FP	92	2144	91	2376	82	2250	80	2303	71	2089	74	2243	82	2234
RT 7331 MA	94	2207	91	2384	82	2249	80	2310	72	2125	74	2238	82	2252
RT 7401	95	2239	93	2432	84	2313	82	2349	75	2210	75	2286	84	2304
RT 7421 FP	95	2247	92	2408	85	2345	82	2356	74	2203	75	2286	84	2307
RT 7521 FP	95	2246	92	2416	86	2377	84	2408	77	2293	80	2411	86	2356
RT XP753	94	2222	91	2384	84	2313	81	2333	74	2179	73	2234	83	2279
RT 7302	94	2214	92	2424	85	2345	82	2349	75	2217	74	2253	84	2300
RTv7231 MA	90	2104	86	2226	80	2187	79	2271	70	2074	68	2090	79	2159
Taurus	93	2191	91	2377	82	2249	81	2326	73	2155	74	2245	82	2257
Titan	93	2175	89	2321	81	2226	81	2333	73	2163	74	2243	82	2244
Mean	95	2250	92	2405	85	2349	83	2383	76	2241	75	2282	84	2319
$LSD_{(\alpha=0.05)}$[a]	1.92	61.10	2.49	79.21	1.88	NS	2.69	81.22	2.39	68.88	1.78	50.39	4.46	49.96

[a] LSD = least significant difference.

Table 5. Influence of seeding date on DD50 accumulations and days from emergence to 50% heading of selected rice cultivars in studies conducted at the University of Arkansas System Division of Agriculture's Northeast Rice Research and Extension Center during 2022.

	Seeding Date													
	21 March		4 April		19 April		28 April		17 May		1 June		Average	
Cultivar	days	DD50 units	days	DD50 units	days	DD50 units	days	DD50 units	days	DD50 units	days	DD50 units	days	DD50 units
Addi Jo	104	2479	93	2425	90	2402	92	2588	80	2355	86	2487	90	2455
ARoma22	99	2319	88	2257	88	2346	91	2583	84	2473	81	2370	88	2398
Avant	100	2351	89	2297	85	2259	90	2541	84	2440	77	2268	87	2360
CLL16	103	2431	93	2401	89	2387	92	2603	87	2555	83	2415	90	2469
CLL17	100	2335	88	2265	88	2362	90	2554	84	2454	82	2387	88	2398
CLL18	106	2532	91	2353	90	2418	90	2539	87	2555	85	2452	91	2472
CLM04	102	2399	92	2393	90	2425	91	2568	85	2492	83	2420	89	2454
DG263L	99	2320	87	2233	84	2235	88	2491	78	2305	73	2145	84	2287
Diamond	101	2383	90	2313	87	2337	90	2547	86	2523	82	2395	88	2414
Ozark	103	2436	92	2369	88	2361	91	2582	84	2461	81	2363	89	2428
PVL03	101	2383	91	2353	89	2384	91	2561	85	2480	83	2410	88	2433
RT 7321 FP	97	2258	88	2265	85	2259	88	2476	78	2297	79	2308	85	2315
RT 7331 MA	100	2335	89	2273	85	2267	89	2506	83	2421	77	2268	86	2346
RT 7401	101	2367	88	2257	87	2315	89	2520	83	2441	81	2374	87	2380
RT 7421 FP	100	2351	90	2313	86	2307	89	2506	84	2460	80	2357	87	2385
RT 7521 FP	101	2367	89	2297	86	2299	89	2513	83	2436	85	2453	88	2396
RT 7302	99	2319	90	2313	87	2315	90	2540	85	2485	80	2355	87	2394
RTv7231 MA	99	2308	89	2217	84	2227	85	2401	77	2256	74	2191	84	2265
RT XP753	100	2335	89	2289	86	2283	89	2513	80	2359	80	2348	86	2356
Taurus	99	2319	91	2353	87	2315	89	2519	83	2434	78	2295	87	2377
Titan	98	2288	88	2241	85	2267	88	2499	80	2343	76	2232	85	2314
Mean	101	2367	90	2308	87	2322	89	2531	83	2429	80	2347	87	2385
$LSD_{(\alpha=0.05)}$[a]	2.59	82.55	2.22	61.08	1.90	56.26	1.90	54.12	3.10	96.38	2.02	52.23	3.62	57.82

[a] LSD = least significant difference.

[b] NS = not significant.

Table 6. Influence of seeding date on grain yield of selected rice cultivars in studies conducted at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center during 2022.

	Grain Yield by Seeding Date						
Cultivar	**22 March**	**5 April**	**20 April**	**5 May**	**20 May**	**4 June**	**Average**
	(bu./ac)						
Addi Jo	161	171	174	151	133	135	155
ARoma22	133	141	146	138	117	125	133
Avant	178	171	174	155	138	135	160
CLL16	189	184	188	176	162	148	176
CLL17	148	163	145	138	130	92	138
CLL18	196	187	206	194	170	154	184
CLM04	169	174	176	161	151	140	164
DG263L	198	202	198	169	175	190	189
Diamond	193	181	193	160	159	154	173
Ozark	206	195	191	189	162	165	185
PVL03	175	176	175	160	137	137	160
RT 7321 FP	201	203	202	180	162	146	184
RT 7331 MA	227	226	227	193	186	169	206
RT 7401	224	212	225	197	204	178	206
RT 7421 FP	207	202	213	201	193	172	198
RT 7521 FP	202	201	217	181	198	167	196
RT 7302	240	217	217	188	189	191	207
RTv7231 MA	203	212	192	178	170	161	186
RT XP753	205	211	222	191	186	177	199
Taurus	202	204	216	186	170	167	191
Titan	175	163	172	136	126	134	152
Mean	192	190	194	172	163	156	178
$LSD_{(\alpha=0.05)}$[a]	15.71	14.02	16.24	14.85	13.06	17.55	6.39

[a] LSD = least significant difference.

Table 7. Influence of seeding date on grain yield of selected rice cultivars in studies conducted at the University of Arkansas System Division of Agriculture's Northeast Rice Research and Extension Center during 2022.

	Grain Yield by Seeding Date						
Cultivar	21 March	4 April	19 April	28 April	17 May	1 June	Average
	(bu./ac)						
Addi Jo	165	186	192	160	142	154	168
ARoma22	167	175	166	160	134	176	164
Avant	175	192	197	173	104	161	169
CLL16	166	194	200	197	132	160	177
CLL17	153	173	165	146	116	159	154
CLL18	166	212	210	199	167	160	187
CLM04	160	175	177	168	149	144	163
DG263L	194	187	192	194	151	195	186
Diamond	191	203	195	185	141	148	178
Ozark	187	205	211	195	171	157	189
PVL03	163	173	180	159	136	150	161
RT 7321 FP	208	213	231	206	154	197	203
RT 7331 MA	223	231	242	209	153	198	211
RT 7401	205	233	241	235	179	206	219
RT 7421 FP	197	205	231	215	179	188	204
RT 7521 FP	184	219	218	207	192	152	197
RT 7302	222	249	259	235	174	199	225
RTv7231 MA	184	209	199	181	126	180	182
RT XP753	213	231	248	220	152	201	214
Taurus	195	229	221	193	157	182	198
Titan	190	202	200	167	153	145	176
Mean	186	205	208	191	150	172	187
$LSD_{(\alpha=0.05)}$[a]	28.3	16.0	14.7	13.46	31.86	1.65	8.13

[a] LSD = least significant difference.

Table 8. Influence of seeding date on milling yield of selected rice cultivars in studies conducted at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center during 2022.

	Milling Yield by Seeding Date						
Cultivar	**22 March**	**5 April**	**20 April**	**5 May**	**20 May**	**4 June**	**Average**
	----------(%HR/%TR)[a]----------						
AddiJo	56/66	58/66	62/68	64/70	60/69	65/70	61/68
ARoma22	60/67	61/67	60/69	56/69	48/68	64/70	58/68
Avant	56/65	57/65	59/68	58/69	51/67	59/68	56/67
CLL16	54/65	56/65	55/68	57/70	50/69	62/68	55/67
CLL17	57/65	58/65	57/67	57/68	51/67	62/68	56/66
CLL18	47/63	54/64	57/67	58/69	53/68	62/68	55/67
CLM04	61/65	62/66	59/69	55/70	54/69	65/69	59/68
DG263L	52/63	54/63	53/67	50/67	38/67	60/69	51/66
Diamond	51/66	56/66	57/69	57/70	50/69	63/70	56/68
Ozark	51/66	54/66	57/69	59/70	54/69	62/69	56/68
PVL03	57/67	60/67	58/69	57/70	49/69	63/70	57/68
RT 7321 FP	54/65	57/67	51/70	47/70	30/69	55/70	49/68
RT 7331 MA	58/67	60/68	54/70	49/71	34/69	61/71	52/70
RT 7401	54/66	59/67	55/70	50/70	38/70	63/70	53/69
RT 7421 FP	53/65	58/67	55/70	52/70	39/70	63/71	53/69
RT 7521 FP	54/65	59/66	60/70	60/70	58/70	63/70	59/68
RT 778	58/67	60/68	55/70	51/70	34/70	63/70	54/69
RTv7231 MA	54/65	55/65	44/67	38/68	29/67	57/70	46/67
RT XP 753	56/67	59/68	53/70	48/71	27/69	57/71	50/69
Taurus	58/66	61/66	58/69	52/70	39/69	62/69	55/68
Titan	60/66	59/65	49/68	41/68	36/67	60/69	50/67
Mean	55/65	58/66	56/69	53/70	44/69	61/69	54/68
$LSD_{(\alpha=0.05)}$ %HR[b]	2.41	2.04	4.27	5.03	6.67	2.49	1.76
$LSD_{(\alpha=0.05)}$ %TR	1.34	1.29	0.91	0.84	1.09	0.91	0.24

[a] %HR/%TR = percent head rice/percent total rice.

[b] LSD = least significant difference.

Table 9. Influence of seeding date on milling yield of selected rice cultivars in studies conducted at the Northeast Rice Research and Extension Center during 2022.

	Milling Yield by Seeding Date						
Cultivar	21 March	4 April	19 April	28 April	17 May	1 June	Average
	----------(%HR/%TR)[a]----------						
AddiJo	64/69	65/70	63/70	64/70	60/68	64/71	63/70
ARoma22	64/69	65/70	64/69	64/70	62/69	65/70	64/70
Avant	61/68	63/69	63/69	63/70	59/68	63/69	62/69
CLL16	61/69	62/70	60/70	62/70	61/70	60/69	61/69
CLL17	57/65	60/67	60/68	60/68	59/68	63/69	60/68
CLL18	62/68	61/69	61/70	62/70	61/69	63/69	62/69
CLM04	63/69	66/70	66/70	66/70	65/70	66/70	65/70
DG263L	58/68	56/68	55/68	58/69	56/68	60/68	57/68
Diamond	59/69	62/70	60/69	62/71	60/69	62/69	61/70
Ozark	65/71	66/72	63/71	64/71	63/70	62/69	64/71
PVL03	63/70	64/70	63/70	62/70	61/69	64/70	63/70
RT7321FP	61/70	63/71	60/71	61/72	56/70	62/70	61/71
RT7331MA	64/71	65/72	64/72	65/73	58/70	66/72	64/72
RT7401	64/70	63/71	63/71	63/72	61/70	66/71	63/71
RT7421FP	64/71	62/71	62/71	65/72	61/70	64/71	63/71
RT7521FP	64/71	64/71	62/71	64/71	62/70	59/68	62/70
RT778	57/67	65/72	65/72	66/73	62/70	66/71	64/71
RTv7231MA	60/68	60/69	59/69	59/69	60/69	65/71	61/69
RTXP753	66/72	65/72	64/72	63/73	58/70	65/72	63/72
Taurus	63/70	66/71	65/71	63/70	62/69	65/69	64/70
Titan	64/68	66/70	65/70	62/70	62/69	64/69	64/69
Mean	62/69	63/70	62/70	63/71	60/69	63/70	62/70
$LSD_{(\alpha=0.05)}$ %HR[b]	NS	1.5	1.74	2.18	2.99	1.55	1.14
$LSD_{(\alpha=0.05)}$ %TR	NS	0.67	0.77	0.67	1.58	0.87	0.58

[a] %HR/%TR = percent head rice/percent total rice.

[b] LSD = least significant difference.

Influence of Nitrogen Strategy on Performance of Selected Hybrids in Arkansas

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Abstract

Hybrid rice (*Oryza sativa* L.) accounts for over 50% of Arkansas rice acres annually. The objective of this research is to determine the optimal nitrogen (N) fertilizer rates for new hybrids across different soils and environments in the Arkansas rice production region. The hybrids RT 7302, RT 7321 FP, and RT 7421 FP were evaluated at a range of preflood N rates. Previous studies have found that a 2-way split application (preflood and boot) increases grain and milling yields combined with reduced lodging. Therefore, a boot N application was made to all treatments. However, to reevaluate the benefits of the boot N application, 2 additional treatments were included to compare with and without boot N. The results of this single year of study suggest that all the hybrids evaluated achieve near-optimal yields at 90–120 lb N/ac. However, additional years of study are needed to make this recommendation which differs from past research.

Introduction

The purpose of this research was to conduct nitrogen (N) rate studies on current hybrid rice cultivars and determine their response with preflood and with the late-boot N application in regard to grain yield, milling yield and lodging. The effect of N has proven to be an essential nutrient on the growth of plants. However, it is not found readily available within crop production. Previous studies have found that a 2-way split application (preflood and boot) increases grain and milling yields combined with a reduction in lodging. These studies aim to build on previous research by evaluating new hybrids in their response to N rate strategy. In 2022, studies were conducted at 4 locations in Arkansas representing the different rice production regions and across soil types.

Procedures

The hybrid x N fertilizer rate studies were established at the following University of Arkansas System Division of Agriculture (UADA) research locations: the Northeast Research and Extension Center (NEREC), Keiser, Ark., on a Sharkey Clay (Vertic Haplaquepts) soil; the Northeast Rice Research and Extension Center (NERREC), Harrisburg, Ark., on a silt loam (Glossaquic Fragiudalfs) soil; the Pine Tree Research Station (PTRS) near Colt, Ark., on a Calloway silt loam (Glossaquic Fragiudalfs) soil; and the Rice Research and Extension Center (RREC), near Stuttgart, Ark., on a Dewitt silt loam (Typic Albaqualfs) soil.

The experimental design utilized for data analysis for all locations and each cultivar was a randomized complete block design with 4 replications per location. All experimental plots were direct-seeded with a plot size 17.5 ft long with 8 rows on 19 cm row spacing. The 3 hybrids used in this study were RT 7321 FP, RT 7302, and RT 7421 FP. All seed was treated with the company's standard seed treatment packing including insecticide and fungicide treatments. The experimental plots received preflood N at rates of either 0, 60, 90, 120, 150, or 180 lb N/ac followed by a second N application at late boot of 30 lb N/ac. Two additional treatments were included at the 90 and 120 lb N/ac preflood N rates that receive no late boot N application.

At maturity, the 4 center rows of each plot were harvested and weight and moisture were recorded. A subsample of harvested grain was collected for selected treatments for milling purposes. Grain yield was adjusted to 12% moisture and reported on a bushel per acre (bu./ac) basis. The dry rice was milled to obtain data on percent of head rice and percent of total white rice (%HR/%TR). Statistical analysis was conducted using PROC GLM, SAS v. 9.4 (SAS Institute, Inc., Cary, N.C.) with means separation using Fisher's least significant difference test ($P = 0.05$).

Results and Discussion

The main effect of boot N application significantly increased the grain yield for all 4 locations to an extent observed between boot N treatments. The influence of N fertilizer at the tested preflood rates on RT 7302 the grain yield was observed to vary slightly between locations (Table 1). At NEREC, the 90–180 lb N/ac rates did not differ. At NERREC, all treatments were greater than the untreated. At PTRS, 120–180 lb N/ac were the highest-yielding N rates. At RREC, 90–150 lb N/ac rates did not differ. The treatments with the highest numerical yields at each location were 180 lb N/ac, 120 lb N/ac, 180 lb N/ac, and 90 lb N/ac at NEREC, NERREC, PTRS, and RREC, respectively.

The influence of N fertilizer preflood rates on RT 7321 FP the grain yield was observed to vary slightly between locations (Table 2). At NEREC, 150 lb N/ac was the highest-yielding treatment, greater than 60–90 lb N/ac. At NERREC, the 150 lb N/ac

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rate was higher yielding compared to the 0 and 90 lb N/ac rates. For the PTRS location, yields for the 120–180 lb N/ac rates were greater than the 0 and 60 lb N/ac rates. For the RREC, all N rates produced higher yields compared to the untreated control. The treatments with the highest numerical yields at each location were 150 lb N/ac, 150 lb N/ac, 150 lb N/ac, and 120 lb N/ac at NEREC, NERREC, PTRS, and RREC, respectively.

Table 3 shows the influence of N fertilizer preflood rates on RT 7421 FP. For the NEREC location, the 120- and 150-lb N/ac rates had greater yields than the 60- and 90-lb N/ac rates. At NERREC, all rates produced higher yields compared to the untreated. For the PTRS, 180 lb N/ac produced higher grain yields than the 60 and 90 lb N/ac treatments. At the RREC, all treatments resulted in higher grain yields compared to the untreated. The treatments with the highest numerical yields at each location were 150 lb N/ac, 120 lb N/ac, 180 lb N/ac, and 120 lb N/ac at NEREC, NERREC, PTRS, and RREC, respectively.

Averaged across cultivars and locations, where 30 lb N/ac at late boot was applied resulted in higher grain yields compared to no boot N applied (Table 4). In addition, there was an increase in head rice and total rice milling yields when boot N was applied (Table 5).

Practical Applications

The hybrid x N fertilizer trials are essential in the assessment of new hybrid rice cultivars as well as developing a N timing regimen to maximize grain yield and productivity. The objective of this study is to determine hybrid rice cultivars' response to N and late-boot N application in regard to grain yield, milling yield and lodging. This scientific study was conducted on representative soils as well as diverse growing environments throughout the Arkansas rice-growing region. The results of these trials can be utilized to determine the optimal rate for N maximizing grain yield for the 3 hybrids in response to the soil type as well as environmental conditions. Results also provide that the grain yield and milling benefited from the current preflood N application as well as boot N application.

Acknowledgments

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Table 1. Influence of nitrogen (N) fertilizer at the preflood N rate application on grain yield (bu./ac) of RT 7302 hybrid rice by location during 2022.

N Fertilizer Rate	Grain Yield			
	NEREC[†]	NERREC	PTRS	RREC
(lb N/ac)	----------------------	(bu./ac)	----------------------	
0	112.9 c[‡]	167.4 b	121.9 d	153.7 c
60	179.7 b	215.1 a	183.2 c	190.7 b
90	193.9 ab	220.8 a	207.4 b	203.7 a
120	212.8 a	228.2 a	219.3 ab	201.6 a
150	204.5 ab	223.0 a	236.3 a	200.1 ab
180	216.4 a	226.3 a	236.9 a	----------
P-value	<0.0001	<0.0001	<0.0001	<0.0001

[†] NEREC = Northeast Research and Extension Center, Keiser, Ark.; NERREC = Northeast Rice Research and Extension Center, Harrisburg, Ark.; PTRS = Pine Tree Research and Extension Center, Colt, Ark.; RREC = Rice Research and Extension Center, Stuttgart, Ark.

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

Table 2. Influence of nitrogen (N) fertilizer at the preflood N rate application on grain yield (bu./ac) of RT 7321 FP hybrid rice by location during 2022.

	Grain Yield			
N Fertilizer Rate	**NEREC[†]**	**NERREC**	**PTRS**	**RREC**
(lb N/ac)	-----------------------	---(bu./ac)---	-----------------------	
0	95.3 d[‡]	145.1 c	112.7 c	143.9 b
60	149.8 c	193.8 ab	173.7 b	186.9 a
90	160.5 bc	193.2 b	195.1 ab	190.0 a
120	178.9 ab	204.1 ab	205.2 a	196.8 a
150	189.7 a	211.4 a	211.8 a	195.1 a
180	185.7 ab	200.2 ab	208.6 a	191.5 a
P-value	<0.0001	<0.0001	<0.0001	<0.0001

† NEREC = Northeast Research and Extension Center, Keiser, Ark.; NERREC = Northeast Rice Research and Extension Center, Harrisburg, Ark.; PTRS = Pine Tree Research and Extension Center, Colt, Ark.; RREC = Rice Research and Extension Center, Stuttgart, Ark.

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

Table 3. Influence of nitrogen (N) fertilizer at the preflood N rate application on grain yield (bu./ac) of RT 7421 FP hybrid rice by location during 2022.

	Grain Yield			
N Fertilizer Rate	**NEREC[†]**	**NERREC**	**PTRS**	**RREC**
(lb N/ac)	-----------------------	---(bu./ac)---	-----------------------	
0	95.9 c[‡]	158.6 b	118.1 d	120.9 b
60	167.8 b	200.8 a	182.7 c	168.7 a
90	191.0 ab	210.5 a	202.7 bc	179.7 a
120	199.2 a	212.6 a	212.8 ab	180.7 a
150	209.7 a	208.2 a	220.2 ab	172.1 a
180	184.1 ab	206.6 a	230.4 a	169.0 a
P-value	<0.0001	<0.0001	<0.0001	<0.0001

† NEREC = Northeast Research and Extension Center, Keiser, Ark.; NERREC = Northeast Rice Research and Extension Center, Harrisburg, Ark.; PTRS = Pine Tree Research and Extension Center, Colt, Ark.; RREC = Rice Research and Extension Center, Stuttgart, Ark.

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

Table 4. Influence of nitrogen (N) fertilizer on rice grain yield (bu./ac) at the boot growth stage averaged across location[†] and cultivar[‡] in 2022.

Boot N Rate	**Grain Yield**
(lb N/ac)	**(bu./ac)**
0	192.3 b[§]
30	199.6 a
P-value	0.0003

† Locations include the Northeast Research and Extension Center, Keiser, Ark.; Northeast Rice Research and Extension Center, Harrisburg, Ark.; Pine Tree Research Station, Colt, Ark.; Rice Research and Extension Center, Stuttgart, Ark.

‡ Cultivars include RT 7302, RT 7321 FP, and RT 7421 FP.

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

Table 5. Influence of nitrogen (N) fertilizer on rice milling yield (% head rice/% total rice) at the boot growth stage averaged across location† and cultivar‡ in 2022.

Boot N Rate	Milling Yield
(lb N/ac)	%HR/%TR
0	47.37 b/61.80 b§
30	48.27 a/62.36 a
P-value	0.0359/0.0042

† Locations include the Northeast Research and Extension Center, Keiser, Ark.; Northeast Rice Research and Extension Center, Harrisburg, Ark.; Pine Tree Research Station, Colt, Ark.; Rice Research and Extension Center, Stuttgart, Ark.

‡ Cultivars include RT 7302, RT 7321 FP, and RT 7421 FP.

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

Continuous In-Season Urea Ammonium Nitrate Fertigation of Furrow Irrigated Rice Through a Novel Pitless Tailwater Pump

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

Abstract

A study was conducted to evaluate the potential of applying 32% Urea Ammonium nitrate (UAN) through fertigation on a furrow-irrigated rice field at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center, near Stuttgart, Ark. The 40-acre field has been no-till since 2018 and utilizes 30-in. raised beds. The UAN was applied 12 times between green ring and boot through the tailwater return from a novel patented pitless pump system. Nitrogen (N) was applied in water through a chemigation valve installed at the pitless pump. Replicated continuously fertigation yields were 181 bu./ac using 124 lb N/ac compared to 169 bu./ac fertilized pre-irrigation with 175 lb N/ac irrigated every 3 days. Tissue N and Normalized Difference Vegetation Index (NDVI) were used to track adequate N in the fertigated treatment and the study demonstrates that fertigation can be used successfully in a pitless tailwater return system and has potential to optimize in-season N with weekly NDVI measurement. Such an approach is useful as the continuous irrigation system is believed to achieve higher yields, while the continuous irrigation system and fertigation approach may provide for both maximum yield potential from water management, while reducing N fertilizer costs.

Introduction

Current N fertilizer recommendations for furrow irrigated rice in Arkansas on a silt loam is a 3-way split, 2-way split or applied pre-flood. For the 3-way split, the first application should be just before irrigation begins. The next 2 applications are recommended to be spaced 7–10 days apart. Sequential applications generally prevent the use of ground equipment for applications (Hardke, 2021). In a study of N rates in furrow irrigated rice, Chlapecka et al. (2021) found that splitting the N over 3 applications totaling the rate recommended for flooded rice (120 lb N/ac) resulted in the highest relative yields at both the top and bottom of the field (Chlapecka, 2021). A single application was able to achieve numerically higher yields (although not significant) but required an additional 50 lb N/ac (180 lb N/ac). This is most likely due to the higher volatilization of nitrogen in the aerobic soil condition present in a furrow-irrigated field. However, in a traditional furrow irrigated rice (FIR) field, the additional N or split applications come at an increased cost of N or application trips, reducing profitability.

The use of fertigation for N application in a furrow-irrigated rice field has the potential to reduce N volatilization by limiting the time the fertilizer is left unincorporated into the soil. An added benefit is that no equipment is required to pass through the field but instead N is added during normal irrigation events. A study by Bhuyan et al. in Bangladesh found that a lower rate of N in a furrow-irrigated rice field using fertigation yielded greater than a conventional flood-irrigated field (Bhuyan, 2014). Previous studies have fertigated Urea Ammonium nitrate (UAN) and liquified urea from the top of the field. In this study, UAN was applied from the bottom of the field, using the pitless tailwater pump, such that the fertilizer was also continuously delivered to the rice field with the return water. With the potential benefits of fertigation, this study was conducted to assess the feasibility of using fertigation to apply N nearly continuously between green ring and boot growth stages, using the tailwater return in a furrow- irrigated rice field in Arkansas. Fertigating from the bottom of the field using the pitless return system is much easier to implement than from the top of the field, because power is available for the fertigation pump at the tailwater pump. The same result may be achievable in a conventional furrow irrigated field; however, the application of N would need to be done to dry soil. By using the pitless pump return, the system can be irrigated and fertilized at the same time with no dry soil events needed to apply fertilizer. This approach provides the pitless tailwater FIR system a considerable advantage and control over soil water and N simultaneously, which is not possible in a conventional FIR system.

A challenge in furrow fertigation is that dry soil intake rates are considerably higher than saturated soil intake rates. When fertigating from the top of the field in a dry soil condition, the advance time and fertilizer flow rate must be managed to coincide with each other to ensure fertilizer does not exit the field as tailwater and that water and fertilizer are uniformly applied along the length of the furrow. However, in a pitless tailwater recovery system, the tailwater is returned continuously, which keeps the soil at a constant saturated intake rate or permeability, which ensures fertilizer is uniformly applied down furrow and allows fertigation to be applied at any point in time rather than only at times when the soil is dry enough for the higher intake rate.

Procedures

This study was conducted at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center

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near Stuttgart, Ark. in 2022. The soil in the field is predominately a DeWitt Silt Loam, which was identified through the USDA Web Soil Survey. The field has been in continuous furrow-irrigated rice since 2016 and no-till since 2017 (last year of tillage). The beds are on 30-in. centers and in the fall of 2021, a bedder-roller was pulled through the field, without any other cultivation, to reform the beds.

This study assessed using a novel tailwater recovery system to furrow irrigate and fertilize rice and compared it to conventional furrow-irrigated and fertilized rice. The field is 1300 ft. long and is end blocked to hold approximately 6 in. of water at the bottom of the field. To continuously irrigate the fertigated plots, a small pump is placed at the bottom of the field which returns the tailwater to the crown (top) of the field. When there is adequate water held at the bottom of the field, the tailwater pump recirculates the water through pipe at the top of the field. When the water at the bottom of the field drops to a level that is not sufficient for the tailwater pump, water is then pumped from a hydrant into the field until the tailwater is refilled.

Because the water is continuously recirculated, it is possible to add fertilizer slowly into the irrigation water. The goal was to apply the fertilizer as UAN multiple times from 4-leaf rice until the boot stage. This in theory would reduce the amount of N lost through volatilization due to the N being applied at a rate more comparable to the rate at which the plants uptake N. This was accomplished by using an Inject-O-Meter IOM-96 pump which could pump a low volume of UAN directly into the tailwater pump return pipe. The application rate of fertilizer can be seen in Fig. 1.

The first treatment was fertigated with UAN at a rate of 124 units of N applied through the irrigation system. The other 2 treatments were fertilized with coated urea applied at 180 lb of N/ac at 4-leaf rice. One of the urea treatments was irrigated every 3 days and the other was irrigated every 7 days. Each treatment had 3 plots that were 30 ft. wide (12 rows) by 1300 ft. long. Two single rep treatments were also included in the study. The first was a plot that was continuously irrigated and fertigated but received an additional 180 units of N as coated urea to serve as a reference N plot for Normalized Differential Vegetation Index (NDVI) comparison to the fertigated treatments. The other was a plot that only received the coated urea and no fertigation but was irrigated continuously. It was necessary to split the field with the fertigated and reference plots on one side and the 0-, 3-, and 7-day irrigated plots on the other side due to the fertigated side containing N in the irrigation water. This prevented a true strip plot design because it was not possible to fertigate plots and include them within the urea treatments. However, the analysis assumes the variation between the 2 areas in the field is the same and randomly distributed. All other inputs are the same between the treatments.

Tissue samples and NDVI readings were taken weekly from green ring until the boot stage in the fertigated, reference, and 0 day urea plots. Samples were taken from the top, middle, and bottom of each plot. The NDVI readings were taken with a Trimble Greenseeker© instrument once just after canopy closure and 2 more times before the boot stage. Readings were taken at the top, middle, and bottom of the plots.

RT 7521 FP was planted on 29 April at a rate of 21 lb/ac. A burndown application of Gramoxone SL 2.0 (48 oz/ac) was applied, and a residual of Command (12.8 oz/ac), Facet (22 oz/ac), and League (3.2 oz/ac) was applied on 30 April. Clincher (15 oz/ac) and Zurax L (21 oz/ac) were applied on 19 May and the field was flushed to activate the chemical. The last herbicide application was Preface (4 oz/ac), Gambit (2 oz/ac), and RiceOne (30 oz/ac) on 5 June. The last herbicide application was Postscript (6 oz/ac) and Basagran (32 oz/ac) on 20 June. After a rainfall event from June 8–10, the continuous irrigation was started for the fertigated treatment and the reference plot and the irrigation schedule were started for the 3- and 7-day interval irrigation treatments. Yield was determined by harvesting the middle 20 ft. of each plot down the 1300 ft. length of the field using a CaseIH 1620 combine and CaseIH 1010 rigid platform head.

Fertilizer presence in the irrigation return water was measured with an Electrical Conductivity (EC) meter during application and for days after fertigation ceased. In general, within about 3 days the EC readings returned to baseline levels indicating that after 3 days the rice consumed the fertilizer in the return water. It was not possible to fertigate when fresh irrigation water was added to the system as it may have resulted in fertilizer being preferentially applied to part of the field.

Results and Discussion

The first NDVI readings were taken 1 month after the urea was applied to the non-fertigated plots and when just over 60 units of N had been applied to the fertigated plots. A value of 85% of the reference strip was used as the threshold for N deficiency as outlined in the Arkansas Rice Production Handbook. The NDVI indicated that the fertigated treatment was deficient of N in the middle and bottom of the plots on July 6 but sufficient on the top of the plots (Table 1). Over the following week, 25 more units of N were added to the fertigated plots. The NDVI readings for July 11 showed that all sections of the field had sufficient N with the lowest section being the middle at 86% NDVI of the reference plot. By 18 July, a total of 112 units of N had been applied to the fertigated plots and the lowest NDVI reading for the fertigated plots was the middle at 90% of the reference plot. The 0-day urea plot never recorded a NDVI reading that was lower than 97% of the reference plot.

The results from the tissue samples that can be seen in Fig. 1 suggest that sufficient N is 2.6–3.2% tissue N at panicle initiation. The samples taken just after panicle initiation showed an average of 3.27% N in fertigated plots. The urea fertilized plot was higher at 4.09% N and the reference plot was much higher at 5.16% N. The tissue samples are useful for comparing between treatments. While there is not much data for what levels of tissue N is considered sufficient in fertigated rice, it is useful to compare the % N between the different treatments until boot. The reference plot maintained a relatively high tissue % N up until the boot stage, where a total of 292 lb N/ac was applied. The urea fertilized plot, 175 lb N/ac, did have higher concentrations of tissue N earlier in the season but by the boot stage the fertigated and urea fertilized tissue concentration was nearly the same by the end of the season.

The fertigated treatment had an average yield of 181 bu./ac (Table 2). Compared to the fertigated, the average yield for the 3-day treatment was 169 bu./ac (P = 0.1726) and the 7-day treatment averaged 163 bu./ac (P = 0.0338). The 3- and 7-day treatments are comparable to how the average furrow-irrigated rice field is managed in Arkansas. The continuously irrigated fertigation treatment is only possible, without much higher of tailwater runoff in a traditional FIR system, without the use of the novel tailwater recovery system. The fertigated treatment received 56 lb N less than the 3- and 7-day treatments and yielded 12 and 18 bu./ac higher. The fertigated and the 7-day treatments had a similar water use efficiency (WUE) at 7.59 bu./in and 7.83 bu./in ($P = 0.6942$), respectively. The 3-day treatment had a significantly lower WUE of 5.59 bu./in ($P = 0.0004$).

The 0-day urea and reference plots yielded 171 bu./ac and 175 bu./ac, but neither was a replicated plot so no statistical analysis can be done to determine any differences. However, their yields are less than the fertigated study, but likely would not be significant. Since all were irrigated continuously, one would have expected that the yields of the 0-day urea and reference plot would have been slightly higher than the fertigated plot. One would expect excess N would result in slightly more but not significant yield, whereas in this case it's less. The data suggest that high yields can be maintained by properly delivered N in the irrigation water, although more research is needed to better determine optimum rates and timings for a fertigated furrow irrigated rice field. One challenge with fertigation is that often some N is needed earlier than the first irrigation, thus a small amount of N at planting time would be helpful to ensure the rice plant has enough N early in life. This would then set up the system to deliver N when the rice plant is likely using the bulk of N in the mid-to-late vegetative phase and when irrigation would be required. Using NDVI during the season to prescribe N may be a useful tool in managing N in-season in the fertigation system.

As mentioned earlier, NDVI measurements shown in Table 2 suggest that the fertigation events between 6 July and 18 July indicate that the three events that total around 25 lb N/ac increased the difference between the reference and plot by 4–5% on average. However, when compared to Fig. 1, tissue N, the plant tissue does not show a response to the fertigation events. Thus, the small amount of N fertigated in that period was adequate to create a substantial change in the NDVI, but not the tissue N. Clearly, however, the fertigated treatment was not yield limited by N or soil water. More research is needed to better explain how N and water interact in a rice fertigation system.

Practical Applications

The novel tailwater recovery system and season-long fertigation show potential to improve yields while also applying less fertilizer N in furrow irrigated rice. Fertigation in furrow-irrigated rice worked well using the pitless tailwater pump as it was easy to implement with power readily available at the tailwater pump to deliver fertilizer to the system. The system eliminated the need for extra-preflood N to achieve optimum yield and reduced application cost. The approach also allows for micronutrient additions, during the season and spreads the labor requirement out for N management. The study applied most N between green ring and boot, the rapid vegetative growth stage; no N was applied during the preflood timeframe, and some N was applied during grain-fill which likely did not contribute to yield. While yield potential is likely stabilized by ensuring adequate N is applied during the season, the study suggests additional yield and/or N use efficiency may be possible through applying N at times not typically possible to apply N in flooded production systems. Conceivably the system may allow for more precise and prescriptive N management, potentially providing a new way to optimize N application in-season using a weekly NDVI prescription.

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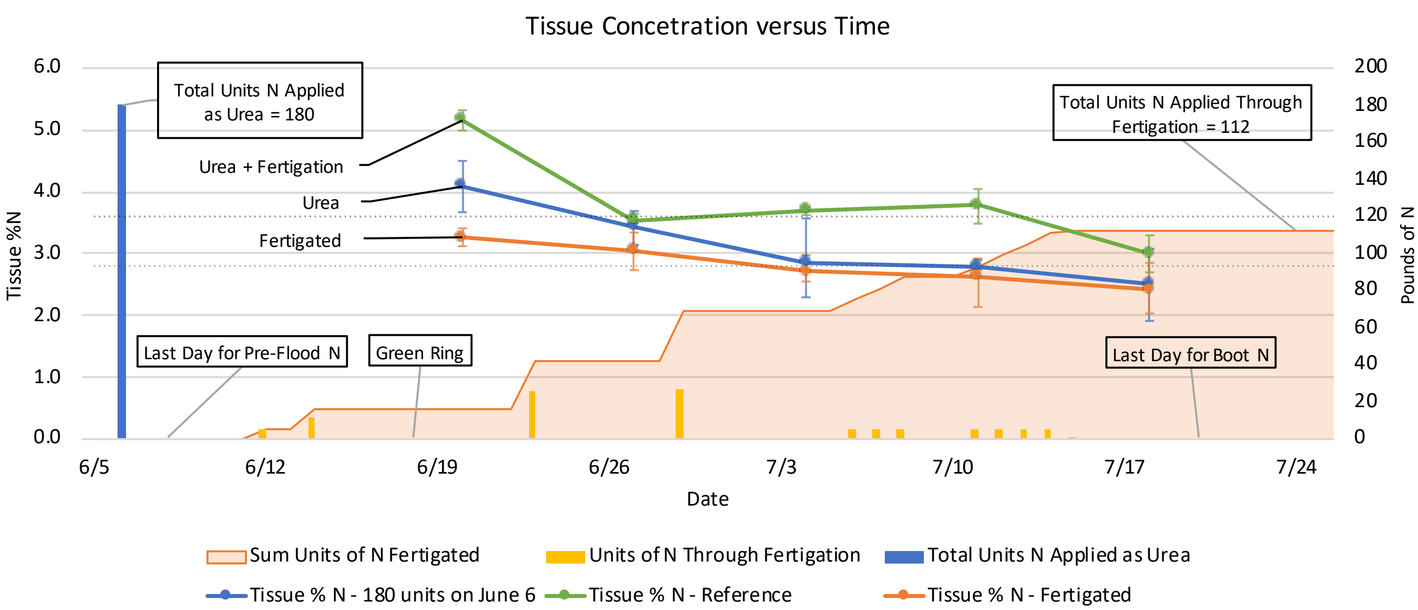

Fig. 1. Sum of Urea applied (blue) and UAN fertigated (red) over time.

Table 1. The Normalized Difference Vegetation Index (NDVI) of the Urea Ammonium nitrate (UAN) fertigated treatment, the reference plot which was fertigated with UAN and had urea applied, the 0 day plot which only had urea applied. Expressed as percent of reference plot NDVI where <85% is considered deficient of nitrogen.

	% Reference NDVI		
Treatment	**6 July**	**11 July**	**18 July**
	---% ---		
Reference Average	100	100	100
Fertigation Top	90	97	97
Fertigation Middle	81	86	90
Fertigation Bottom	85	89	92
0 Day Urea	98	99	97

Table 2. Yield (bu./ac), irrigation water use (ac-in./ac), and water use efficiency (bu./in) for irrigation varying irrigation treatments.

Treatment	**Yield**	**Rainfall**	**Water Use**	**Water Use Efficiency**	**Number of Replications**
	(bu./ac)	**(in.)**	**(ac-in./ac)**	**(bu./in.)**	**(*n*)**
Fertigated	181 a†	6.4	17.3	7.59 a	3
3 Day	169 a	6.4	23.8	5.59 b	3
7 Day	163 b	7.2	13.6	7.83 a	3
Reference	175‡	6.4	17.3	7.37‡	1
0 Day	170‡	6.4	57.0§	2.46‡	1

† Means within a column followed by different letters are significantly different at P = 0.05 level. Tukey's honestly significant difference method used for mean comparison.

‡ Indicates data from un-replicated plots that cannot be compared with significance to other plots.

§ Assumes total volume irrigation water applied and not recovered through a tailwater system. 17.3 ac-in./ac would be consumptive.

Effect of Cover Crops on Yield in Furrow Irrigated Rice

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

Abstract

A study was conducted to evaluate a novel cover crop crimper and to evaluate the yield difference when cover crops were seeded in the fall and burndown herbicides were not used. The study was conducted at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center, near Stuttgart, Ark. on a Dewitt silt loam soil. The field was set up with a variable flow tailwater recovery system (VFTWRS) that recirculates water from the bottom of the field to the crown. No significant yield penalty was measured for the cover crop treatment although numerically the yield was 11 bu./ac less. The first preemergent herbicide application and burndown were not applied to the cover crop treatment; rather the crimper was used to attempt to reduce weed pressure and terminate the cover crop.

Introduction

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 continuous tillage system than the no-till system, but lower yield in 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.

Different ways are available to terminate cover crops. Herbicides can be used to terminate cover crops, but another method uses a roller crimper to break the stems of plants and terminate cover crops mechanically. However, to date no cover crop crimper has been developed for furrow irrigation where the ground is not flat. Very little research exists on how to utilize cover crops in rice. A challenge with rice is that the optimum planting window for rice is mid-April before when most cover crops reach anthesis and can be crimped with a roller crimper. This study investigated the use of a novel cover crop crimper to terminate a cover crop in furrow irrigated rice using the crimper to replace the burn-down and pre-emergent herbicide application traditionally used in rice production.

Procedures

This study was conducted at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center near Stuttgart, Ark. in 2022. The soil in the field is predominately a DeWitt silt loam, which was identified through the USDA Web Soil Survey. The field has been in continuous furrow-irrigated rice since 2016 and no-till since 2017 (last year of tillage). Raised beds were constructed on 30 in. spacing using a bedder-roller in 2017, and each subsequent year a Perkins furrow runner was used to reconstruct a narrow furrow while leaving the beds intact. The field was planted with RT7521 FP on April 29 at a rate of 21 lb/ac.

Two treatments were observed: cover crop and no cover crop. Both treatments were replicated 3 times each in a randomized strip design. Each plot was 30 ft. (12 rows) by 1300 ft. The cover crop treatment was planted at 25 lb/ac in the fall of 2021 with 50% annual rye (*Lolium perenne* L.), 25% cowpeas (*Vigna unguiculata*), 12.5% crimson clover (*Trifolium incarnatum*), and 12.5% Daikon radish (*Raphanus sativus* var.). Before planting, the cover crop was crimped with an experimental crimper that can crimp on the top and bottom of the beds. No burndown or residual herbicide was applied at planting to the cover crop treatment. The no cover crop treatment was not planted with a cover crop and received a burndown application of Gramoxone SL 2.0 (48 oz/ac) as well as a residual of Command (12.8 oz/ac), Facet (22 oz/ac), and League (3.2 oz/ac) at planting.

The first herbicide that the cover crop treatment received was Clincher (15 oz/ac) and Zurax L (21 oz/ac), which both treatments received on 19 May. The second herbicide application for the cover crop treatment and third herbicide for the no cover treatment was on 5 June. This application consisted of Preface (4 oz/ac), Gambit (2 oz/ac), and RiceOne (30 oz/ac). The last herbicide application was Postscript (6 oz/ac) and Basagran (32 oz/ac) on 20 June.

The field was furrow irrigated using a novel tail water recovery system that recirculates the water that is held at the bottom of the field through the lay-flat pipe at the top of the field. When there is not adequate water held at the bottom of the field, water is added from a hydrant. This allows the field to be irrigated continuously. Fertilizer was added through the irrigation using urea ammonium nitrate (UAN) at a rate of 125 lb N/ac.

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Results and Discussion

Crimping the cover crop was only partially successful. The crimper was able to crimp a majority of the cover crop, but some on the edge of the bed was pushed down but the stems were not broken. The cover crop was crimped before anthesis, so it was not as effective as it should have been; most of the plants did die except the annual ryegrass. The main reason for the reduced cover crop stand is that it was observed that waterfowl consumed the cover crop about 3 times during the winter. It was also observed that where rice stubble was still standing, the cover crop was denser. The cover crop did not have enough above-ground biomass to adequately shade out the emerging weeds. As a result, there was weed pressure and annual ryegrass pressure suppressing rice growth in the cover crop treatment until the application of Preface on June 5. The no-cover crop treatment, in contrast, did not experience weed pressure because of the preemergent herbicides. Because of the increased weed pressure, it is not surprising that the cover crop treatment yielded lower than the no cover crop treatment, however the magnitude of the yield penalty is not as severe as expected. The average yield (Table 1) was 182 bu./ac for the cover crop treatment and 193 bu./ac for the no-cover treatment. This was not a significant difference; however, it is approaching significance ($P = 0.0584$).

While it is true that there was no significant difference between the cover and no cover treatments, whether a crimped cover crop is a viable alternative to a preemergence herbicide is encouraging. The cover crop treatments did receive fewer herbicides but relied on the mid-season application to reduce weed pressure. Additionally, many of the winter annuals matured before the mid-season herbicide application, which likely contributed more to the weed seed bank than if a burndown had been applied. Finally, the addition of a control treatment without a cover crop where no pre-emerge herbicide is applied would be helpful in future studies to evaluate the weed pressure and yield penalty. Because the cover crop was established it likely suppressed other weed establishment, although at a cost to the rice.

This was the first test of a novel cover crop crimper in rice. One challenge is that the normal rice planting window is before the maturity of most of the cover crop mix. Thus, for cover crops to reach anthesis and be mature enough for crimping may require a later rice planting date. However, the crimper was successful at pushing over and breaking some of the later cover crops plants, so if the cover crops were better established and were more mature, it's likely that the crimper would have provided more benefit. Future research should focus on finding cover crops that would mature in April when the optimum window for rice is or another termination method may be needed.

Practical Applications

Crimping cover crops in a no-till furrow irrigated field presents a few challenges that still have not been solved. The varying bed height and shape across a field is the greatest complication. The experimental crimper that was used showed potential but still needs further development to better crimp the side of the furrow. Another hindrance is producing enough above-ground biomass to provide a dense enough layer of green mulch. A late fall cover crop planting date in addition to geese feeding on the cover crop, contributed to a weaker-than-necessary cover crop stand. Planting soon after harvest can allow more cover crop growth in the fall. The observation that cover crop density was higher in rice stubble than burned stubble areas suggests that leaving rice stubble intact may reduce waterfowl damage to the cover crop. More work to plant into high-residue rice stubble may be warranted to take advantage of this for cover crops. This same finding has been observed in corn stalk cover crop applications.

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Table 1. Yield (bu./ac) for cover crop and no cover crop treatments.

Treatment	Yield
	(bu./ac)
No Cover Crop	193 a[†]
Cover Crop	182 a

[†] Means within a column followed by different letters are significantly different at P = 0.05 level. Tukey's honestly significant difference method was used for mean comparison.

Bed Condition for Furrow Irrigated Rice: Refreshed Versus No-Till

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

Abstract

This study evaluated the effects of re-pulling beds in a no-till system. After the 2021 season, the beds had gone 5 growing seasons since they had been formed. Each spring, a furrow runner was pulled through the field to clean out the furrows, but the beds were still highly eroded and nearly flat. Both the bedded and un-bedded treatments consisted of 3 plots each that were 30 ft. by 1300 ft. long. Both plots stayed above field capacity until the field was drained, but the bedded treatment maintained a 2–3% lower volumetric water content (VWC). The no-till beds had consistently higher VWC during the season by between 2–5% volumetric water content. The average yield for the no-till, un-bedded plots (193 bu./ac) was significantly higher than the rebedded plots of 181 bu./ac ($P = 0.0304$). The results provide additional evidence that any tillage in a no-till system will reduce yield.

Introduction

Flood irrigation uses about 24 to 32 acre-in. of water in one growing season (Henry et al., 2013). Some other irrigation methods, like the alternate wetting and drying and furrow irrigation, have started to gain interest. In 2019 there was a 10% increase in acreage using furrow irrigation for rice (Hardke and Chlapecka, 2020). Other than the water-saving benefits, there are other advantages associated with growing furrow-irrigated rice. These include savings in levee construction and removal, easier access to the field during harvest, and a reduction in greenhouse gas emissions (Vories et al., 2002; Adhya et al., 2014). Also due to the quicker drying of the field, it is easier to use ground equipment for operations such as fertilization and chemical treatments, which can significantly reduce the total production cost. One disadvantage is that some studies have found a yield reduction when using furrow irrigation (Vories et al., 2002; Singh et al., 2006; Chlapecka, 2020). Furrow-irrigated rice has the potential to greatly impact rice production practices in the region. However, one challenge in furrow-irrigated rice is whether to rebuild beds or leave them intact for the rice production year. Worn-down beds can result in poor water distribution the following year because irrigation may erode a bed, leaving a bed dry without irrigation. Thus, a common practice is to re-build or re-hip beds by passing a bedder roller across the field after the stubble has been burned.

Bed height is an issue in that a taller bed is more likely to maintain and contain the water distributed to each furrow in lay-flat pipe. However, water is less likely to infiltrate all the way across a bed when a bed is pulled deep enough to ensure irrigation water streams will not break them over. The common recommendation is a “lazy” bed or bed height of about 3–4 inches, whereas a common row crop bed is about 5 inches.

Procedures

This study was conducted at the University of Arkansas System Division of Agriculture’s Rice Research and Extension Center near Stuttgart, Ark. in 2022. The soil in the field is predominately a DeWitt silt loam, which was identified through the USDA Web Soil Survey. The field has been in continuous furrow-irrigated rice since 2016 and no-till since 2017 (last year of tillage).

This study looked at the effect of re-pulling beds in a no-till system. After the 2021 season, the beds had gone 5 growing seasons since they had been formed. Each spring, a furrow runner was pulled through the field to clean out the furrows, but the beds were still highly eroded and nearly flat. Some sections differed by less than 1 in. between the top and bottom of the beds. In addition to holes produced by animals, this resulted in many dry furrows. To re-form the beds, a roller bedder was pulled through the field after the rice was harvested in 2021. The resulting beds had approximately 5 in. between the top and bottom of the beds. The re-bedding was done by first burning the field and then pulling the bedder, without first cultivating, the field. No cultivation was done to maintain a reduced tillage practice. Three plots were left un-bedded and only a furrow runner was used as a control treatment.

Both the bedded and un-bedded treatments consisted of 3 plots each that were 30 ft. by 1300 ft. long. Due to extenuating circumstances, the treatments were not able to be set up in a randomized block design but were adjacent to the other within the same field. Except for the bedding, both treatments were treated the same in all regards. The field was planted on 29 April with RT7521 FP at a rate of 21 lb/ac. The field was furrow irrigated using a novel tail water recovery system that recirculates the water that is held at the bottom of the field through the lay-flat pipe at the top of the field described in Kandpal (2018). When there is not adequate water held at the bottom of the field, water is added from a hydrant. This

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allows the field to be irrigated continuously. Fertilizer was added through the irrigation using urea ammonium nitrate (UAN) at a rate of 125 lb N/ac. Yield was determined by harvesting the middle 20 ft. of each plot down the length of the field.

Soil moisture was measured using a Acclima TDR-315R sensor placed on the top of the bed. One sensor was placed in the center of the first replication of each treatment. The sensors were read using an AquaTrac unit that recorded the readings over the season at 15-min. intervals. The data was recorded in percent (%) volumetric water content (VWC). Allowable depletion (AD) was calculated using 35.6% VWC as field capacity and 8.9% VWC as permanent wilting point. Yield was determined by harvesting the middle 20 ft. of each 30 ft. wide by 1300 ft long plot down the length of the field using a CaseIH 1620 combine and CaseIH 1010 rigid platform head.

Results and Discussion

Figure 1 shows the volumetric water content (VWC) of both the bedded and un-bedded treatment from the late vegetation stage until harvest. Both plots stayed above field capacity until the field was drained, but the bedded treatment maintained a 2–3% lower VWC. This is likely due to the taller bed height. Another reason for the lower VWC of the beds may be a potential boundary layer or interface of dissimilar soils that was created between the soil that was moved from the bottom of the furrows to on top of the old beds that may have caused an issue with infiltration. However, since the soil had an entire winter to reconsolidate it is unlikely this was a factor and the reason for the yield differences is due to tillage.

The average yield, shown in Table 1, for the unbedded plots was 193 bu./ac and 181 bu./ac for the re-bedded plots (P = 0.0304). It is difficult to determine the reason for the lower yield resulting from pulling new beds. The lower average VWC may be the primary cause. The volumetric water content of the no-till and re-formed beds is shown in Fig. 1. The no-till beds had consistently higher volumetric water content during the season by between 2–5% volumetric water content. In general, the range was higher than 40% volumetric water content until late in the season, both well above field capacity (35.6% VWC). The probes take an average across the length, so with the taller reformed beds, it's likely some soil would have been drier at the top of the bed in the reformed bed than the no-till bed and this may be an explanation for the yield difference. However, in theory the soil water should have been adequately available, and no differences in yield would have been expected.

Another potential contributing factor was the disturbance of the soil structure that had been developed from 5 years of no-till management. It was observed that there were dry furrows in the old bed plots caused by water breaking over the short beds. This likely did not create any water stress in the dry furrows due to the continuous irrigation allowing the water to permeate across the beds. Had there been water stress in the dry furrows, it likely would have reduced the overall yield. It should be noted that maintenance of beds is a common problem; as beds break over, the irrigator must shovel soil back to force water down each furrow.

Practical Applications

The beds in a no-till furrow irrigated fields inevitably wear down year to year and require maintenance. This study indicates that there may be a reduction in yield if beds are pulled too deep. It also suggests that as long as there is enough of a bed to prevent an excessive number of dry furrows, it may not be necessary to pull new furrows for growing furrow-irrigated rice. More research would be helpful in determining the best balance height of beds for furrow irrigated rice.

Acknowledgments

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Table 1. Yield (bu./ac), irrigation water use (ac-in./ac), and water use efficiency (bu./in.) for cover crop and no cover crop treatments.

Treatment	Yield
	(bu./ac)
Re-Bedded	181 b[†]
Old Beds	193 a

[†] Means within a column followed by different letters are significantly different at $P = 0.05$ level. Tukey's honestly significant difference method was used for mean comparison.

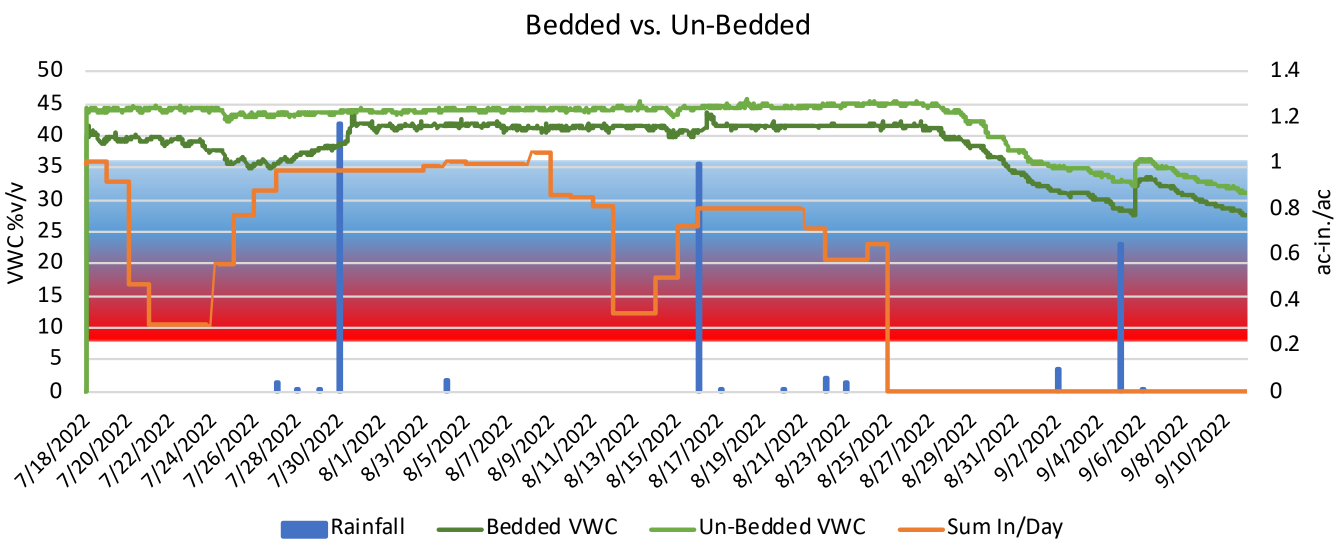

Fig. 1. Soil moisture in volumetric water content of one replication of the no-till (un-bedded) and re-formed bed (bedded) treatments.

Evaluating Irrigation Timing, Depletion, Water-Use and Efficiencies in Furrow-Irrigated Rice

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

Abstract

A study was conducted to determine the allowable depletion in furrow-irrigated rice that results in yield penalty. The study was conducted at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center, near Stuttgart, Ark. on a Dewitt silt loam soil. The field was set up with a variable flow tailwater recovery system (VFTWRS) that recirculates water from the bottom of the field to the crown. Irrigation treatment timings applied to plots as continuously irrigated using the VFTWRS continuously and irrigation every 3, 7, 10, and 14 days. Yield was highest for the continuous irrigation treatment at 180 bu./ac and lowest for the 14-day irrigation treatment at 138 bu./in. Water use efficiency was only significantly lower for the 3-day irrigation treatment compared to the other treatments. There were only 7.2 inches of rain experienced in the field in 2022; as a result, it was not possible to maintain an average allowable depletion of less than 50% in the 7-, 10-, and 14-day treatments. Only 17 ac-in./ac of total water was applied to the continuous irrigation treatment, while 23.8 ac-in./ac was applied to the 3-day treatment. While not significant, the continuous irrigation treatment resulted in a higher yield (11.9 bu./ac), 6.8 ac-in/ac less irrigation, 51 lb N/ac less fertilizer, and a significantly higher water use efficiency of 2 bushels per inch than the 3-day treatment. The data and results from this study strongly suggest the importance of maintaining adequate water in the soil profile for furrow-irrigated rice. Where yields have been maintained by seasonal rainfall in past studies, this was not possible in 2022 and yield penalties and soil water deficits were greater than in previous studies.

Introduction

In the United States, Arkansas is the largest producer of rice. In 2019, Arkansas rice producers harvested 1,126,000 acres with an average yield of 167.7 bu./ac (USDA-NASS, 2019). This represents 45.6% of total U.S. rice produced and 47.1% of the total acres planted with rice in the US (Hardke, 2019).

Irrigation is one important input to for obtaining maximum yield in furrow-irrigated rice (FIR). Among row crops in the U.S., rice is one of the largest consumptive users of irrigation water. For farmers in Arkansas, much of the irrigation water is provided by groundwater, and much of that is from the Mississippi River Alluvial aquifer. However, the groundwater levels throughout the Mississippi River Alluvial aquifer are declining. One study found an average decline of 1.44 ft in wells across the aquifer for the 2012–2013 season (Arkansas Natural Resource Commission, 2014).

The most common system of irrigation for rice in Arkansas is flooding (Vories et al., 2002). Flood irrigation uses about 24 to 32 acre-in. of water in one growing season (Henry et al., 2013). Some other irrigation methods, like the alternate wetting and drying and furrow irrigation, have started to gain interest. In 2019, there was a 10% increase in acreage using furrow irrigation for rice (Hardke and Chlapecka, 2020). Other than the water-saving benefits, there are other advantages associated with growing furrow-irrigated rice. These include savings in levee construction and removal, easier access to the field during harvest, and a reduction in greenhouse gas emissions (Vories et al., 2002; Adhya et al., 2014). Also due to the quicker drying of the field, it is easier to use ground equipment for operations such as fertilization and chemical treatments which can significantly reduce the total production cost. One disadvantage is that some studies have found a yield reduction when using furrow irrigation (Vories et al., 2002; Singh et al., 2006; Chlapecka, 2020). Furrow-irrigated rice has the potential to greatly impact rice production practices in the region. Because of this, it is important to study the different methods and technologies to improve production using furrow irrigation in rice.

Procedures

This study was conducted at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center near Stuttgart, Ark., in 2022. The soil in the field is predominately a DeWitt silt loam, which was identified through the USDA Web Soil Survey. The field has been in continuous furrow-irrigated rice since 2016 and no-till since 2017 (last year of tillage). The beds are on 30-in. centers and in the fall of 2021, a bedder-roller was used through the field, without any other cultivation, to reform the beds. It should be noted that beds were repulled in the fall and were formed much higher than in previous years. Thus during the season, the beds were much higher than would be normal in a FIR field; as a result, less breaking over between furrows was observed.

The study consisted of 4 irrigation interval treatments of 3, 7, 10, and 14 days between irrigations in a replicated strip plot design.

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In an adjacent area of the field a continuous irrigation treatment was applied because it was not physically possible to locate the continuous irrigation treatment next to the interval treatments. The field was separated into 12 plots that were 30 ft. wide (12 rows) by 1300 ft. long resulting in 3 replications for each treatment. The bottom of the field was blocked to maintain a flood of 5 inches. Consequently, the bottom 200 ft. of the field remained flooded after the first irrigation until the drain down date. Yield was determined by harvesting the middle 20 ft. of each plot down the length of the field.

Irrigation was provided using a 12-in. lay-flat pipe with a 3/8-in. hole punched on every row. Hole size was determined using PHAUCET. Water was measured using a McCrometer propeller meter and a Seametrics AG90 mag meter. The meters were read before and after each irrigation event. Water use efficiency (WUE) was calculated in bu./in. by dividing yield by irrigation plus rainfall. Rainfall was calculated using a tipping bucket rain gauge. Rainfall was calculated from emergence (6 May) until two-thirds tan-colored panicles (26 August for the 3-day and 1 September for the 7-, 10-, and 14-day).

The irrigation management was split into 2 time periods. The first period was during the vegetative growth stage. During this time, a target of 1.5 in. of water was applied during each irrigation event over a 24-hr time period. This resulted in the 3-day treatment receiving approximately 3 in./wk, the 7 day receiving 1.5 in./wk, the 10 day receiving 1 in./wk, and the 14 day receiving 0.75 in./wk. If there was a rainfall event of over 1 in., the schedule was reset. For any rainfall event of less than 1 in., the schedule was delayed accordingly. The second period of irrigation management started after panicle initiation. During this time, a target of 2 in./wk was set for the 7-, 10-, and 14-day treatments. To accomplish this, the time between irrigations was not altered but instead the time period that an irrigation event lasted was increased to replace evapotranspiration (ET). The goal was to create some stress during the vegetative growth stage but meet crop water demand during the reproductive growth stage, although 2 in./wk would likely not be adequate to meet full crop water demand, but was all that the soil appeared to hold because of a soil sealing effect. For a 14-day irrigation cycle, 3.5 ac-in./ac would need to be applied if crop water demand was near 0.25 inches per day. However, because of soil sealing effects, it's not practical to apply this application depth, so the 10- and 14-day irrigation treatments would likely have needed to mine sub-soil moisture to meet crop water demand.

RT7521 FP was planted on 29 April at a rate of 21 lb/ac. A burndown application of Gramoxone SL 2.0 (48 oz/ac) was applied, and a residual of Command (12.8 oz/ac), Facet (22 oz/ac), and League (3.2 oz/ac) was applied on 30 April. Clincher (15 oz/ac) and Zurax L (21 oz/ac) were applied on 19 May and the field was flushed to activate the chemical. The next herbicide application was Preface (4 oz/ac), Gambit (2 oz/ac), and RiceOne (30 oz/ac) on 5 June. The last herbicide application was Postscript (6 oz/ac) and Basagran (32 oz/ac) on 20 June. Coated urea was applied on 6 June at a rate of 175 lb N/ac on the interval treatments, whereas the continuously irrigated treatments were fertigated with 124 lb N/ac using 32% UAN. After a rainfall event from June 8–10, the irrigation schedule was initiated.

Soil moisture was measured using Acclima TDR-310R sensors placed on the top of the bed. One sensor was placed in the center of the first replication of each treatment. The sensors were read using an AquaTrac unit that recorded the readings over the season at 15-min. intervals. The data was recorded in percent (%) volumetric water content (VWC). Allowable depletion (AD) was calculated using 35.6% VWC as field capacity and 8.9% VWC as permanent wilting point.

Yield was determined by harvesting the middle 20 ft. of each plot down the 1300 ft. length of the field using a CaseIH 1620 combine and CaseIH 1010 rigid platform head; samples were tested for moisture and test weight. The experiment was a strip plot design, and data were analyzed using JMP v. 17.0 (SAS Institute, Inc., Cary, N.C.). A two-way analysis of variance (ANOVA) test was used with multiple pair-wise comparisons using Tukey's honestly significant difference (HSD) at $\alpha = 0.05$.

Results and Discussion

The growing season was dry with only 7.2 inches of rain during the growing season and only 3 inches in July and August. This resulted in visible stress in the 10- and 14-day treatments during the vegetative stage due to the irrigation not providing enough water to refill the soil profile and inadequate rain to meet crop water demand.

The highest yield was recorded in the continuously irrigated (0 day) treatment of 181 bu./ac (Table 1). No significant difference in yield was found between 0-, 3-, and 7-day irrigations; however, there was a numeric difference of 11.9 bu./ac. The fertigated treatment used 51 lb N/ac less than the interval treatments, suggesting that the treatment effect was due to water not N. It is believed that 175 lb N/ac should have been more than an adequate N fertilization rate for FIR. Yield was significantly different between 0, 3, and 7 days, and 10 and 14 days. However, the allowable depletion (AD) measured in the soil is not numerically different; the 7-, 10-, and 14-day treatments had similar average and highest allowable depletions as shown in Table 2. Allowable depletions over 50%, and 40% in past research are thought to accumulate stress units in plants so some yield penalty is expected at depletions higher than 40–50%. It was observed in the 3-day that the average allowable depletion was 16% but experienced at least one event at 57%, while the continuously irrigated field experienced an average AD of 7% and the highest at 62%. Thus, one would not expect a yield difference between the 2 treatments and while not statistically significant was numerically 11.9 bu./ac higher for the continuously irrigated treatment. While not significant, there is clearly a break in AD and yield between 3 and 7 days as the 7 day has a slightly lower yield (6.6 bu./ac) but experienced much higher allowable depletions of an average of 70% and max of 85% well into the expected stress zone. The yield penalty for water stress is not a crisp break in this research. It is likely a gradual relationship between when and to what degree rice experiences stress and the response in metabolic processes that then reduces yield to compensate.

A significant difference in WUE was observed between 3 day and the other treatments. This is significant because to maintain a low allowable depletion with this high-frequency irrigation it also required 23.8 ac-in./ac whereas the continuous irrigation was only 17 ac-in./ac. While less water was achieved with the 7 day, it also came at a much lower yield than the continuous irrigation and no significant improvement in WUE.

Less rainfall was accumulated in the 0- and 3-day irrigations; this is because the treatments varied by maturity and growth stage by about 3–4 days between treatments. That is, the continuous irrigation treatment was consistently about 3–4 days ahead of the 3-day treatment, then the 7 day was about 3–4 days behind the 3-day treatment and so forth. Thus, about a 2-week difference existed between the 0-day and the 14-day treatment. This was likely due to the water stress that occurred during the growing season. It should be noted that this was an excessively dry year for the study; only 6.4–7.2 inches of rain occurred during the season compared to 13.8 inches in 2019, 16.6 in 2020 and 17.4 in 2021. In previous years, rainfall likely has obscured the irrigation treatment and soil water balance differences.

Samples were milled using a Zaccaria PAZ-1 DTA laboratory rice mill (Zaccaria, Brazil) for the irrigation treatments. No significant difference in total head rice yield was found for the 0-, 3- and 7-day treatments corresponding to 7% 15% and 70% AD. There was a difference in total head rice yield for 10-day and 14-day treatments. The allowable depletions for 10 day were 64% and 68% for 14 day both very near to the AD for 7 day. No significant difference was found in head rice yield for 0-, 3-, 7- and 10-day treatments. The results suggest that milling yields only are reduced under extreme water stress or very high allowable depletions or low-frequency irrigations. The continuous irrigation system does not appear to improve milling yields compared to more common 3- or 7-day irrigations where allowable depletions are kept in a reasonable range for soil water depletions (<50%). So likely keeping irrigation ADs in the recommended range of 0–40% should not result in reductions of total or head rice yields.

Practical Applications

The data and results from this study demonstrate and strongly suggest the importance of maintaining adequate water in the soil profile for furrow-irrigated rice. Where yields have been maintained by seasonal rainfall in previous years in conventionally irrigated FIR, this was the not the same climatic scenario in 2022 where only 6.4–7.2 inches of rainfall was experienced. Thus irrigation frequency and application amount was a key factor in yield potential. As a result, yields were likely reduced due to the inability to maintain adequate water to FIR, even on fields with a high irrigation frequency. However, the pitless pump system/continuous irrigation system appears to have been able to achieve a higher yield, while conserving nitrogen, using less irrigation water, and improving water use efficiency over a high-frequency 3-day irrigation schedule. Data also suggest that reductions in total and head rice yields are not expected to decrease until 60–70% allowable depletion (current recommendations are <40%).

Acknowledgments

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Table 1. Yield (bu./ac), rainfall (in.), irrigation water use (ac-in./ac), and water use efficiency (bu./in.) for irrigation varying irrigation treatments.

Treatment	Yield	Rainfall	Water Use	Water Use Efficiency
	(bu./ac)	(in.)	(ac-in./ac)	(bu./in.)
0 Day (Fert)/ 7% AD†	181.0 a‡	6.4	17.3	7.59 a
3 Day /16% AD	169.1 a	6.4	23.8	5.59 b
7 Day / 70% AD	162.5 a	7.2	13.6	7.83 a
10 Day / 64% AD	144.5 b	7.2	12.9	7.20 a
14 Day / 68% AD	138.7 b	7.2	10.8	7.70 a

† AD = allowable depletion.

‡ Means within a column followed by different letters are significantly different at P = 0.05 level. Tukey's honestly significant difference method used for mean comparison.

Table 2. Yield, average % volume water content before irrigation, average % volume water content range before irrigation, average allowable depletion before irrigation, and highest allowable depletion before irrigation for varying irrigation treatments.

Treatment	Yield	% VWC Before Irrigation Event	% VWC Before Irrigation	Average AD before Irrigation	Highest AD just before Irrigation
	(bu./ac)	(% AVG)	(range %)	(% AVG)	(%)
0 Day / 7% AD†	181 a‡			7	62
3 Day / 16% AD	169.1 a	31.2	20.3–36.9	16	57
7 Day / 70% AD	162.5 a	16.9	12.8–24.4	70	85
10 Day / 64% AD	144.5 b	18.6	14.4–30.4	64	79
14 Day / 68% AD	138.7 b	17.3	10.9–29.6	68	93

† AD = allowable depletion.

‡ Means within a column followed by different letters are significantly different at P = 0.05 level. Tukey's honestly significant difference method used for mean comparison.

Table 3. Milling yield by irrigation treatment.

Treatment	%TR†	%HR‡
0 Day / 7% AD§	0.678 a¶	0.591 a
3 Day / 15% AD	0.685 a	0.590 a
7 Day / 70% AD	0.675 ab	0.587 a
10 Day / 64% AD	0.656 c	0.566 ab
14 Day / 68% AD	0.642 d	0.544 b

† Percent total white rice yield.

‡ Percent total head rice yield.

§ AD = allowable depletion.

¶ Means within a column followed by different letters are significantly different at P = 0.05 level.

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

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

Abstract

The University of Arkansas System Division of Agriculture's Irrigation Yield Contest was conducted between 2018 and 2022. The contest was designed to promote better use of irrigation water and to record data on water use and water use efficiency. Unlike yield contests, where winners are decided by yield alone, the irrigation contest results are decided by the highest total Water Use Efficiency (WUE) achieved. Irrigation water was recorded by using 6-, 8-, 10-, and 12-in. portable mechanical flow meters. Rainfall totals were calculated using Farmlogs™. The average WUE measured in the contest between 2018–2022 for rice was 4.99 bu./in. The winning WUE was 7.84 bu./in. for 2022, 9.77 bu./in. for 2021, 8.72 bu./in. for 2020, 7.24 bu./in. for 2019, and 7.8 bu./in. for 2018. Adoption of irrigation water management (IWM) practices such as computerized hole selection (CHS), surge irrigation, and soil moisture sensors, have increased since the first year of the contest. Fifty-six percent of entries have used the furrow irrigation production system in 2020, 2021, and 2022. On average, rice growers in the contest across the 5 years averaged 197 bu./ac, 28.8 ac-in./ac of irrigation, and a total water use of 43.5 in.

Introduction

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

Arkansas is the largest producer of rice in the U.S., producing 45.6% of the total rice in the U.S. (Hardke, 2019). The most common method of irrigation for rice is flood irrigation (Vories et al., 2002). Producers in Arkansas using flood irrigation use approximately 24–32 ac-in./ac of water (Henry et al., 2013). This equates to rice production using roughly half of all water taken from the Mississippi River Alluvial Aquifer in Arkansas (Kresse et al., 2014).

A study was conducted from 2013 to 2017 in primarily corn and soybean fields to assess the water-saving potential of implementing 3 irrigation water management (IWM) tools: computerized hole selection (CHS), surge irrigation, and soil moisture sensors (Spencer et al., 2019). Paired fields were set up with using the IWM tools and 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 corn fields, a 40% reduction in water use was observed and WUE was 51% higher for IWM fields. For soybeans, no significant difference in net returns was found, but in corn, net returns were significantly improved by adopting IWM.

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 producers. The competition aimed to promote water-reducing management practices by educating producers on the benefits of irrigation water management tools, providing feedback to participants on how they compared to other producers, documenting the highest achievable water use efficiency 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. 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 180 bu./ac must be achieved to qualify.

A portable propeller-style mechanical flowmeter was used to record water use. All flow meters were checked for proper installation and sealed using polypipe tape and serialized tamper-proof cables. Rainfall was recorded using Farmlogs™, an online software that provides rainfall data for a given location. Rainfall amounts were totaled from the date of emergence to the predicted drain date. Emergence was assumed as 7 days after the planting date provided on the entry form. The University of Arkansas System Division of Agriculture DD50 Rice Management Program was used to find the predicted drain date for the rice field (Hardke et al., 2020). Rainfall is adjusted for extreme events.

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

The equation used for calculating WUE for the contest was: WUE = Y/(Pe + IRR) where, WUE = water use efficiency in bushels per inch, Y = yield estimate from harvest in bushels per acre, Pe = Effective precipitation in inches, and IRR = Irrigation application in ac-inches/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 (www.uaex.uada.edu/irrigation) for each year of the contest. Over the 5 years that the competition has been conducted, there have been 62 fields entered for rice. The average WUE over the 5 years was 4.99 bu./in. By year, the average WUE was 5.81 bu./in. for 2022 with 11 contestants, 5.46 bu./in. for 2021 with 6 contestants, 4.69 bu./in. for 2020 with 22 contestants, 5.16 bu./in. for 2019 with 6 contestants, and 5.17 bu./in. for 2018 with 11 contestants (Table 1). The 2018 and 2019 seasons both had a higher average WUE than 2020. In 2020, there were more contestants in rice than in 2018 and 2019 combined. This may partially explain the lower WUE because more variation is expected with a larger number of growers. The winning WUE was higher in 2021 and 2022 than in 2018, 2019, and 2020. The highest (winning) WUE for each year was 7.94 bu./in. for 2022, 9.77 bu./in. for 2021, 8.72 bu./in. for 2020, 7.24 bu./in. for 2019, and 7.80 bu./in. for 2018.

In 2022, subcategories were added for furrow-irrigated rice (FIR) and levee rice. Results for furrow-irrigated rice are detailed in Table 2 and results for levee-irrigated rice are detailed in Table 3. The number of entries in FIR ranged from a high of 15 to a low of 5 per year, with the average of all years being 7.8 entrants/year. In levee rice, the number of entries ranged from a high of 7 to a low of 1, with an average of 3.4 entrants/year. FIR number of entries favored Levee entries by approximately 2:1. The 5-year averages reveal the following: WUE furrow 4.94 bu./in. and levee 5.46 bu./in., yield furrow 193 bu./ac and levee 210 bu./ac, irrigation applied furrow 29.1 ac-in./ac and levee 28.1 ac-in./ac, and total water furrow 43.2 in. and levee 42.3 in.

Additional data is available based on a limited number of participants from levee-irrigated rice. Entrants were asked about their irrigation practices, and divided into three categories, cascade flood, where the water is delivered to paddies by cascading over levee spills. Multiple Inlet Rice Irrigation (MIRI) is the practice of using lay-flat pipe and hole punches or blue gates to distribute water across paddies or levees. Alternate wetting and drying (AWD) includes MIRI but also includes the management practice of allowing the water to recede before reflooding. The use of these practices by entrants and their respective WUE, yield, rainfall and water use are shown in Table 4. Alternate wetting and drying had the highest average WUE of 6.65 bu./in., followed by cascade with a WUE of 5.54 bu./in., and MIRI with WUE of 4.22 bu./in. Average yields between cascade and AWD were identical at 211 bu./ac, but MIRI was less at 184 bu./ac. Irrigation water use was similar between MIRI and Cascade at 32 ac-in./ac for both but much less for AWD (20 ac-in/ac). The sample size for levee practices is a very small sample of each system type.

In 2015, a survey was conducted across the mid-South to determine the adoption rate of various IWM tools (Henry, 2019). On the entry form for the contest, a similar survey was included to assess the usage of IWM tools in the contest entrants. In the 2015 survey, 40% reported using CHS, and 66% of the Arkansas growers reported using CHS. 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 all contest participants reported using the entry form. The IWM tool that was most widely adopted was CHS. The average use among respondents was 82.7% across all 5 years, with 88% in 2018, 72% in 2019, 100% in 2020, 97.5% in 2021, and 79% in 2022. The use of furrow-irrigated rice saw an increase in respondents from 56% and 50% in 2018 and 2019, respectively, to 73% in 2020, 80% in 2021, and 64% in 2022. About 68% of rice contest fields used furrow irrigation in the 5-year history of the contest. Another water-saving method of rice irrigation is MIRI. Twenty-one percent of respondents from all 5 years reported using MIRI with 33% in 2018, 17% in 2019, 27% in 2020, 100% in 2021, and 25% in 2022. Sixty percent of respondents from all 5 years said that they used soil moisture sensors on their farm, with 50% in 2018, 40% in 2019, 42% in 2020, 87% in 2021, and 81% in 2022. Surge valves were the least used IWM tool, with a 5-year average use rate of 25%. Those that reported using surge irrigation over the 5 years of the contest were 44% in 2018, 28% in 2019, 16% in 2020, 35% in 2021, and 12% in 2022 (Table 5).

Practical Applications

Irrigation water use efficiency of working farms is not a common metric available in the literature, and it is not a metric familiar to rice farmers. The data recorded from the Arkansas Irrigation Yield Contest provides direct feedbachk to irrigators about their irrigation performance in maintaining high yields and low irrigation water used. Such direct feedback to Arkansas rice farmers will likely provide many with a competitive advantage when water resources become more scarce. The contest provides a mechanism for rice farmers to evaluate the potential for water savings by adopting water-saving techniques or management changes. On average, rice growers in the contest across the 5 years averaged 197 bu./ac, 28.6 ac-in./ac of irrigation, and a total water use of 43.5 in.

Acknowledgments

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Table 1. Maximum, average, and minimum for 2018, 2019, 2020, 2021, and 2022 of various water and yield data points from the Arkansas Irrigation Yield Contest.

		Water Use Efficiency	Yield	Adjusted Rainfall	Irrigation Water	Total Water
		(bu./in.)	(bu./ac)	(in.)	(ac-in./ac)	(in.)
2022	Maximum	7.94	251	17.1	47.1	64.2
	Average	5.44	178	12.8	23.2	36.0
	Minimum	2.61	125	8.4	8.6	22.6
2021	Maximum	9.77	245	16.5	51.7	66.3
	Average	5.46	216	14.0	29.9	43.8
	Minimum	3.69	183	11.1	13.5	24.5
2020	Maximum	8.72	251	18.1	92.1	104.2
	Average	4.62	196.4	14.8	33.1	49.7
	Minimum	1.55	120.0	11.7	14.0	27.6
2019	Maximum	7.24	209.9	24.0	30.5	48.7
	Average	4.70	190.6	17.7	22.4	42.3
	Minimum	3.55	162.8	13.2	13.4	28.7
2018	Maximum	7.80	266.6	16.0	47.9	63.8
	Average	5.17	208.9	13.7	28.8	42.4
	Minimum	2.84	131.9	7.4	16.0	29.4
5 Yr.	Average	4.99	197.0	14.4	28.8	43.5

Table 2. Maximum, average, and minimum of furrow-irrigated rice for 2018, 2019, 2020, 2021, and 2022 of various water and yield data points from the Arkansas Irrigation Yield Contest.

		Water Use Efficiency	Yield	Adjusted Rainfall	Irrigation Water	Total Water	Entries
		(bu./in.)	(bu./ac)	(in.)	(ac-in./ac)	(in.)	
2022	**Maximum**	7.94	194	17.1	47.1	64.2	
	Average	5.45	164	13.0	20.7	33.7	7
	Minimum	2.61	125	8.4	8.6	22.6	
2021	**Maximum**	9.77	240	16.5	30.5	48.6	
	Average	5.82	210	13.9	25.5	39.4	5
	Minimum	3.77	183	11.1	13.5	24.5	
2020	**Maximum**	6.74	227	18.0	92.1	104.2	
	Average	4.35	193	14.6	35.1	49.8	15
	Minimum	1.51	123	11.7	14.0	30.1	
2019	**Maximum**	4.89	210	24.0	30.5	48.7	
	Average	4.19	187	18.6	24.2	45.0	5
	Minimum	3.55	163	12.7	18.7	38.8	
2018	**Maximum**	6.14	267	16.0	47.9	63.8	
	Average	4.7	201	13.5	30.7	44.2	7
	Minimum	2.84	132	7.4	19	31.6	
5 Yr.	**Average**	4.78	191	14.5	29.1	43.9	7.8

Table 3. Maximum, average, and minimum of levee-irrigated rice for 2018, 2019, 2020, 2021, and 2022 of various water and yield data points from the Arkansas Irrigation Yield Contest.

		Water Use Efficiency	Yield	Adjusted Rainfall	Irrigation Water	Total Water	Entries
		(bu./in.)	(bu./ac)	(in.)	(ac-in./ac)	(in.)	(number)
2022	**Maximum**	7.66	251	14.4	37.8	50.8	
	Average	5.42	202	12.4	27.5	39.9	4
	Minimum	2.91	139	10.4	16.6	28.5	
2021	**Maximum**	3.69	245	14.6	51.7	66.3	
	Average	3.69	245	14.6	51.7	66.3	1
	Minimum	3.69	245	14.6	51.7	66.3	
2020	**Maximum**	8.72	251	18.1	66.6	83.8	
	Average	5.19	203	15.3	28.7	44.0	7
	Minimum	2.39	120	12.6	14.9	27.6	
2019	**Maximum**	7.24	208	13.2	13.4	28.7	
	Average	7.24	208	13.2	13.4	28.7	1
	Minimum	7.24	208	13.2	13.4	28.7	
2018	**Maximum**	7.8	229	15.3	39.8	53.5	
	Average	6.0	223	13.9	25.4	39.3	4
	Minimum	4.2	218	13.3	16.0	29.4	
5 Yr.	**Average**	5.46	210	14.1	28.1	42.3	3.4

Table 4. Levee rice technology 5-yr average summary.

	Water Use Efficiency	Yield	Irrigation Water	Total Water	Total Entries
	(bu./in.)	(bu./ac)	(ac-in./ac)	(in.)	(number)
Cascade	5.54	211	32.2	45.3	5
AWD	6.65	211	20.4	34.1	6
MIRI	4.22	184	32.4	48.1	6

Table 5. Technology adoption from the Arkansas Irrigation Yield Contest (% by respondents).

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

Yield Responses of Pure-Line and Hybrid Rice to Potassium Fertilization

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Abstract

Potassium (K) is one of the most limiting nutrients for rice (*Oryza sativa* L.) grown in the direct-seeded, delayed-flood production system common in the U.S. Mid-South and substantial yield reductions can occur when produced on soils low in exchangeable K. The primary objective of our research was to compare yield responses of pure-line and hybrid rice cultivars to K fertilization in a trial where various K rates (0, 40, 80, 120, and 160 lb K_2O/ac) have been applied annually for several years. With Very Low (<61 ppm) Mehlich-3 K in the no-fertilizer-K control plots, both cultivars responded to K fertilization. Without K application, the pure-line (Diamond) produced 67% of the maximum yield produced when fertilized with K, while the hybrid (RT 7321 FP) produced 53% of the maximum yield. Averaged between cultivars, grain yields of 107, 145, 155, 167, and 177 bu./ac, which were all significantly different, were produced from annual application rates of 0, 40, 80, 120, and 160 lb K_2O/ac, respectively. Grain yields were significantly less from the hybrid (135 bu./ac) than from Diamond (165 bu./ac), averaged among fertilizer-K rates, but the interaction of cultivar and K rate did not influence yields. Grain yields of the hybrid cultivar were lower than expected, likely due to lodging, which decreased as fertilizer-K rate increased. Results of this study suggest that RT 7321 FP may be more responsive to K fertilizer than pure-line cultivars, but recent trials observed another hybrid (RT Gemini 214 CL) to be less responsive. Based on inconsistent responses of hybrid rice to K fertilization and the fact that earlier studies predominantly evaluated pure-line cultivars, it is important to continue studying the response of hybrid rice to K fertilization to build a database for proper interpretation of tissue data and potential adjustments to K fertilizer recommendations.

Introduction

Soil testing is currently the most common method for estimating soil potassium (K) availability and making fertilizer-K recommendations to ensure an adequate K supply to prevent K deficiency in rice. In 2021, 66% of the rice acres produced in Arkansas followed soybean [*Glycine max* (L.) Merr.] and 22% followed a previous rice crop (Hardke, 2022). Based on soil samples submitted to the University of Arkansas System Division of Agriculture's Soil Testing Laboratory in Marianna in 2021, DeLong et al. (2023) reported that 34% of sampled acreage following soybean or rice had Low (61–90 ppm) or Very Low (<61 ppm) Mehlich-3 soil-test K concentrations. The likelihood of a positive rice yield response to K fertilizer is good when soil-test K is considered Low or Very Low, as Slaton et al. (2009) reported a positive yield response to K fertilization in 15 of 19 site-years of Arkansas rice trials where Mehlich-3 K was less than 99 ppm. Of the 31 harvested site-years in the study, 15 did not respond positively to K fertilizer and rice receiving no K fertilizer produced an average yield of 183 bu./ac. Slaton et al. (2009) also showed that responsive sites had an average yield of 158 bu./ac without K fertilizer and 185 bu./ac in the highest-yielding treatments that received fertilizer-K. Appropriate K fertilization of K-deficient rice resulted in yield increases of 6 to 51 bu./ac (up to 48% increase relative to control), indicating the potential of proper K fertilization to substantially increase rice yields on K-deficient soils.

Tissue analysis is another tool that can indicate the nutritional status of a crop, but generally is used to aid in the diagnosis of potential nutrient deficiencies and toxicities rather than to guide nutrient management of U.S. mid-South rice production systems. Recent research (Gruener et al., 2022) has examined changes in tissue-K concentration of Y-leaves from R1 (panicle differentiation) to R3 (50% heading), but previous work with rice has focused only on tissue-K concentration of whole-plant samples collected at R1 or R3, so data is limited for interpretation of K nutritional status in the four to five weeks between the R1 and R3 growth stages. Research in Arkansas (Maschmann et al., 2010) has shown a positive yield response to fertilizer-K applied to rice as late as flag-leaf emergence (R2), indicating the potential to alleviate in-season K deficiency with a proper and timely interpretation of tissue-K concentrations.

The response of hybrid rice to K fertilization has been recently studied in Arkansas (Gruener et al., 2022), but most previous research in Arkansas has been focused on the response of pure-line rice to K fertilization. Dobermann and Fairhurst (2000) indicated that hybrids generally produce more biomass, resulting in greater K demand and requiring more available K than pure-line cultivars. Aboveground plant samples collected at heading from field trials in Arkansas have shown 20% greater K uptake (Slaton et al., 2010) and 17% greater N uptake (Norman et al., 2013) by hybrid rice, relative to a pure-line cultivar. Gruener et al. (2022), however, observed a positive yield response to fertilizer-K in two of five site-years for pure-line rice (average increase of 34 bu./

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ac), while hybrid rice did not respond in any of the five matching site-years. The inconsistent results reported in the literature indicate that additional research investigating rice responses to K fertilization is needed. The objective of this research was to improve our understanding of the yield responses of hybrid and pure-line rice cultivars to K fertilization.

Procedures

Long-term field trials were established adjacent to each other at the University of Arkansas System Division of Agriculture's Pine Tree Research Station (PTRS, Colt, Arkansas) in 2000 and 2002 on a Calhoun silt loam (fine-silty, mixed, active, thermic Typic Glossaqualf) and have been cropped to a 1:1 rice-soybean rotation (one trial is rice and the other is soybean each year). Rice main plots were 16-ft long and 25-ft wide in 2022 on the trial area established in 2000, each accommodating 4 passes with a 9-row drill (7.5-in. row spacing). Composite soil samples from the 0- to 4-in. depth were collected from every main plot prior to fertilization and planting each year. Soil samples were all analyzed for pH (1:2 soil:water mixture) and Mehlich-3 extractable nutrients. Each main plot was split into sub-plots by seeding 2 drill passes with a pure-line (Diamond) and 2 passes with a hybrid cultivar (RT 7321 FP). The seeding rates used in the study were 75 lb seed/ac and 25 lb seed/ac for the pure-line and hybrid cultivars, respectively. The trial contained 8 replicates, each consisting of K-fertilization rates of 0, 40, 80, 120, and 160 lb K_2O/ac. Fertilizer-K treatments were applied on 11 May and planting occurred on 12 May. A uniform application of triple superphosphate (60 lb P_2O_5/ac) was broadcast over all plots at the same time as K-treatment application and a uniform application of urea treated with NBPT (130 lb N/ac) was made prior to flooding at the 5-leaf stage to ensure adequate P and N availability for rice growth. A flood was established within 3 days after preflood-N application and was maintained until dry-down for harvest. Additional rice crop management closely followed the University of Arkansas System Division of Agriculture's Cooperative Extension Service recommendations for direct-seeded, delayed-flood rice production. The middle 5 rows of each drill pass of each plot were harvested with a small-plot combine and grain moisture was standardized to a content of 12% for final grain yield calculation and statistical analysis.

Y-leaf tissue samples were collected from all fertilizer-K rate treatments at the booting growth stage by separating 15 Y-leaf blades at the leaf collar from plants throughout the inside rows of each plot. Tissue samples were dried in a forced-draft oven and tissue was ground to pass a 1-mm sieve prior to digestion by nitric acid and analysis by ICP-AES.

Soil pH and Mehlich-3 extractable K were analyzed as a randomized complete block with K rate as the only factor. The treatment structure for tissue samples and yield data was a split-plot where fertilizer-K rate was the main-plot factor and rice cultivar was the subplot factor. Analysis of variance was performed using the MIXED procedure of SAS v. 9.4 (SAS Institute, Cary, N.C.) and differences were interpreted as significant when the P-value was ≤ 0.10.

Results and Discussion

Mehlich-3 extractable soil K was affected by K application rate in 2022 (Table 1). Soil-test K was greatest from the annual application of 160 lb K_2O/ac and intermediate from the application of 120 lb K_2O/ac, but soil-test K did not differ among annual applications of 0, 40, or 80 lb K_2O/ac. The interaction of K application rate and rice cultivar significantly influenced tissue-K concentration of Y-leaves at the booting growth stage (Table 2). Tissue-K concentration was lowest where no K was applied and, within each cultivar, 160 lb K_2O/ac resulted in greater tissue K than 0 or 40 lb K_2O/ac application rates. For Diamond, 120 lb K_2O/ac also resulted in greater tissue K than 0 or 40 lb K_2O/ac rates. The tissue-K concentration of Diamond was significantly lower than RT 7321 FP where no fertilizer-K was applied, but within each other K-rate treatment, concentrations did not differ between cultivars. These results are generally consistent with the results of this trial in 2021, where cultivar did not influence Y-leaf tissue-K concentrations which increased as fertilizer-K application rate increased (Smartt et al., 2022). Tissue-K concentrations without fertilizer-K were similar in 2021 and 2022 (1.04% and 1.06%, respectively), but averaged 1.73% and 1.45% in 2021 and 2022, respectively, at the highest fertilizer-K application rate. Previous research has suggested that a tissue-K concentration of >1.60% K is required to produce maximal rice grain yield between the panicle initiation (R1) and mid-boot growth stages (R3). Based on the work of Gruener et al. (2022), it appears that both cultivars and all fertilizer-K rates resulted in tissue-K concentrations that were suboptimal (<1.60% K). Gruener et al. (2022) found that the Y-leaf K concentration of rice without added K was nearly constant from the R1 to R3 growth stages, but tissue-K declined during reproductive growth when fertilizer-K was applied. Lower tissue-K concentrations in 2022, relative to 2021 values, may be due to slightly later sample timing in 2022 as K-rate-related differences in Y-leaf K concentration decrease over time.

Rice grain yields in 2022 were influenced by K rate and cultivar, but the interaction of the 2 factors was not significant (Table 2). Averaged among K rates, Diamond produced a yield of 165 bu./ac, while RT 7321 FP averaged 135 bu./ac. Overall, grain yields averaged 17 bu./ac greater in 2022, relative to this trial in 2021 (Smartt et al., 2022), but Diamond produced 22% more grain than RT 7321 FP both years. The yield reduction of the hybrid in 2021 and 2022 may have been related to lodging that only occurred in RT 7321 FP. In 2020, grain yields did not differ between Diamond and RT 7521 FP when no lodging occurred (Smartt et al., 2022). Averaged between the 2 cultivars, grain yields ranged from 107 bu./ac without fertilizer-K, increasing significantly with each increase in K rate, to 177 bu./ac with the application of 160 lb K_2O/ac. In comparison, grain yields of Diamond and RT 7321 FP were maximized with 80 and 120 lb K_2O/ac rates, respectively, in 2020 and 2021. Similarly, grain yields of Diamond did not increase significantly with application rates above 80 lb K_2O/ac in these long-term trials in 2018 or 2019 (Gruener et al., 2019; 2020). A hybrid cultivar was not evaluated in the long-term trials in 2018 and 2019, but Gruener et al. (2019; 2020) observed lower yield responses from a hybrid (Gemini) than from Diamond in matching short-term site-years. Interestingly, in this trial the hybrids were more responsive to fertilizer-K in 2020, 2021, and 2022 than Diamond (average maximum increase of 52 bu./ac for Diamond and 78 bu./ac for the hybrid over those years). Those differences may have been enhanced by lodging in 2021 and 2022, but the hybrid was also more responsive than Diamond when lodging did not occur in 2020 (relative to the control, fertilizer-K increased yields by 33 and 56% for the pure-line and hybrid, respectively). These results are consistent with the generalization by Dobermann and Fairhurst (2000) that hybrids tend to produce more biomass and require more available K than pure-line cultivars.

Based on 8 site-years in 2018 and 2019, Gruener et al. (2022) predicted a critical Y-leaf concentration (to achieve 95% relative yield) of 1.60% for pure-line rice between the R1 and R2 growth stages and 1.3% from R2 to R3. In 2021, Y-leaf samples collected before R2 (when 50% of flag-leaf collars are visible) contained 1.60% tissue-K for pure-line and hybrid rice when 120 lb K_2O/ac was applied, which resulted in 100% relative grain yields (Smartt et al., 2022). Tissue-K, however, was below 1.5% for both cultivars when 80 lb K_2O/ac was applied and relative grain yields of 96% and 86% were produced from Diamond and the hybrid, respectively. Lower Y-leaf tissue-K concentrations in 2022, relative to 2021, would suggest K deficiency at all fertilizer-K application rates, but maximum yields were similar to recent years, and it is unlikely that 160 lb K_2O/ac did not supply adequate K to the rice. Sample timing may partially explain the unexpected tissue-K concentrations in 2022 as Y-leaf samples were collected within a couple of days after the R2 growth stage (more than 50, but less than 100% of flag leaf collars were visible). Based on the critical Y-leaf concentration between R2 and R3, 40 lb K_2O/ac should have produced near-maximum yields for both cultivars, but relative yields of 85% and 78% for the pure-line and hybrid, respectively, resulted from that application rate. Since research indicates a decrease in critical Y-leaf concentration at R2, tissue samples should be collected prior to that growth stage to assess the K nutrition status of rice.

Practical Applications

Three years of data in the long-term K response trials at the Pine Tree Research Station suggest that there are different responses of pure-line and hybrid rice cultivars to exchangeable soil K and K-fertilizer applications. While these results are consistent with the idea of a greater expected K demand for hybrid rice, recent research has shown Gemini, another hybrid, to be less responsive to K than Diamond. The results of this work are somewhat inconclusive but indicate that more research is needed to identify if the tissue-K concentrations proposed by Gruener et al. (2022) are applicable to both pure-line and hybrid rice cultivars. The results of this work coupled with future experiments will aid researchers and producers in identifying the best way to manage fertilizer-K for pure-line and hybrid rice cultivars.

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Table 1. Soil pH (measured in a 1:2 soil:water mixture) and Mehlich-3 extractable soil K means (0-4 inch depth, *n* = 8) as affected by annual fertilizer-K rate in long-term trials at the University of Arkansas System Division of Agriculture's Pine Tree Research Station (PTRS) near Colt, Arkansas, in 2022.

Fertilizer-K rate	Soil pH	Soil-test K
(lb K_2O/ac/yr)		(ppm)
0	7.8	48 c[†]
40	7.7	55 c
80	7.8	53 c
120	7.7	70 b
160	7.7	84 a
mean	7.8	63
C.V. (%)	1.0	12.7
P-value	0.1166	<0.0001

[†] Means in the same column followed by different letters are significantly different ($P \leq 0.10$).

Table 2. Y-leaf tissue-K concentration (%) of rice plants sampled at the booting growth stage and grain yield (*n* = 8) as affected by annual fertilizer-K rate, rice cultivar, and their interaction in a long-term trial at the University of Arkansas System Division of Agriculture's Pine Tree Research Station (PTRS) near Colt, Arkansas, in 2022.

	Tissue-K			Grain yield			Lodging[†]
Fertilizer-K rate	Diamond	RT 7321 FP	K rate mean	Diamond	RT 7321 FP	K rate mean	RT 7321 FP
(lb K_2O/ac/yr)	(%)			(bu./ac)			(%)
0	0.97 f[‡]	1.13 e	1.06	125	88	107 E[§]	83 A
40	1.34 cd	1.33 d	1.33	159	130	145 D	48 B
80	1.40 abcd	1.35 bcd	1.39	173	138	155 C	23 C
120	1.44 ab	1.40 abcd	1.42	181	153	167 B	5 D
160	1.47 a	1.43 abc	1.45	187	167	177 A	0 D
Cultivar mean	1.33	1.34	--	165 A	135 B	--	--
K rate	<0.0001			<0.0001			<0.0001
Cultivar	0.8095			<0.0001			--
Interaction	0.0803			0.5338			--
C.V. (%)	8.6			9.4			29.5

[†] Lodging estimates at harvest; no lodging was observed for Diamond.

[‡] Different lowercase letters next to means indicate significant differences within cultivar and K-rate treatment combinations ($P \leq 0.10$).

[§] Different uppercase letters next to cultivar or K rate means indicate significant differences for that variable ($P \leq 0.10$).

Summary of N-STaR Nitrogen Recommendations in Arkansas During 2022

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Abstract

Seeking to fine-tune nitrogen (N) application, increase economic returns, and decrease environmental N loss, some Arkansas rice (*Oryza sativa* L.) producers are turning away from blanket N recommendations based on soil texture and cultivar and using the Nitrogen Soil Test for Rice (N-STaR) to determine their field-specific N rates. In 2010, Roberts et al. correlated years of direct steam distillation (DSD) results obtained from both 0 to 12 and 0 to 18-in. soil samples to plot-scale N response trials across the state to develop a field-specific, soil-based N test for Arkansas rice. After extensive small-plot and field-scale validation, N-STaR is available to Arkansas farmers for both silt loam and clay soils. Samples submitted to the N-STaR Soil Testing Lab in 2022 were summarized by county and soil texture, totaled 45 fields across 9 Arkansas counties, and were from 19 clay and 26 silt loam fields. Depressed sample submissions were again observed likely due to another wet spring and subsequent planting rush. The N-STaR N-rate recommendations for samples were compared to the producer's estimated N rate, the 2022 Recommended Nitrogen Rates and Distribution for Rice Cultivars, and the standard Arkansas N-rate recommendation of 150 lb N/ac for silt loam soils and 180 lb N/ac for clay soils. Each comparison was divided into 3 categories based on a decrease in recommendation, no change in recommended N rate, or an increase in the N rate recommendation. Soil texture was a significant factor in the standard ($P < 0.0002$) and cultivar ($P < 0.0008$) comparisons; however, county, unlike previous years, was not a significant factor in any of the comparisons for 2022. Further stressing the potential N cost savings opportunities, reductions of 30 lb N/ac or greater were recommended by N-STaR in 76%, 63%, and 77% of fields in the standard, estimated, and cultivar comparisons, respectively.

Introduction

Nitrogen (N) recommendations for rice in Arkansas were conventionally based on soil texture, cultivar selection, and the previous crop, often resulting in over-fertilization, which can decrease possible economic returns and increase environmental N loss (Khan et al., 2001). Searching for a field-based factor to drive N recommendations, scientists obtained several years of 0 to 18-in. soil samples, equivalent to rice rooting depth on a silt loam soil (Roberts et al., 2009), conducted direct steam distillation (DSD) analysis as an estimator of plant available N, correlated to plot-scale N response trials across the state, and developed a site-specific, soil-based N test for Arkansas rice (Roberts et al., 2011). Direct-seeded, delayed-flood rice production, with proper flood management and the use of ammonium-based fertilizers and best management practices, has a consistent N mineralization rate and one of the highest N use efficiencies of any cropping system; therefore, it lends itself to a high correlation of mineralizable-N to yield response (Roberts et al., 2011). After extensive field testing and validation, N-STaR became available to the public for silt loam soils in 2012 with the initiation of the University of Arkansas System Division of Agriculture's N-STaR Soil Testing Lab in Fayetteville, Arkansas. Later, researchers correlated direct steam distillation results from 0 to 12-in. soil samples to N response trials on clay soils (Fulford et al., 2019), and N-STaR rate recommendations became available for clay soils in 2013. Some Arkansas farmers are benefiting from this research by using N-STaR's field-specific N rates, but many continue to depend on soil texture, cultivar, or routine management habits to guide N-rate decisions, which may not always be the most profitable or environmentally sound practice.

Procedures

Samples submitted to the N-STaR Soil Testing Lab for the 2022 growing season were categorized by county and soil texture to evaluate the effect of the N-STaR program in Arkansas. The N-STaR rate recommendations for these samples were then compared to the producer's estimated N rate supplied on the N-STaR Soil Test Laboratory Soil Sample Information Sheet; the 2022 Recommended Nitrogen Rates and Distribution for Rice Cultivars found in the 2022 Rice Management Guide (Hardke et al., 2022); and to the standard Arkansas N-rate recommendation of 150 lb N/ac for silt loam soils and 180 lb N/ac for clay soils. Results were then divided into 3 categories—those with a decrease in N-fertilizer rate recommendation, no change in recommended N rate, or an increase in the N rate recommendation. The resulting data were analyzed using JMP 16 (SAS Institute, Inc., Cary, N.C.) with means separated using Fisher's least significant difference test ($P = 0.05$).

Results and Discussion

Samples were submitted from 45 producer fields across 9 Arkansas counties during the 2022 production year, only 14.8% of the 304 fields sampled in 2013 when the program was initiated, and analysis costs were partially subsidized. Lonoke County ranked first

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in Arkansas rice production acres (USDA-FSA, 2022), and Clay County, ranked sixth, submitted samples from the highest number of fields, 23 and 11, respectively. Samples were submitted by 12 different producers or consultants, including 4 producers in Lonoke County. The average number of fields submitted by client was 3.75. All 2022 samples were received after rice had been planted during the typically wetter spring months when soil sampling at proper moisture is more problematic, as opposed to sampling after harvest of the previous crop. The samples received were from 26 silt loam fields and 19 clay fields (Table 1).

Like previous years, 2022 hit farmers with a wet early spring which only allowed small planting windows scattered across the state and an all too familiar rush when ground was dry enough for planting. When rains and cooler temps did finally break, 2022 Arkansas planted rice acreage totaled to 1.08 million acres, down from the 1.19 million acres of 2021 (USDA-FSA, 2022). Another wet spring coupled with the rush to get rice planted likely led to decreased numbers of samples that would have been submitted for N-STaR analysis. Lonoke County had the highest planted rice estimates (USDA-FSA, 2022) and submitted the highest number of N-STaR samples (Fig. 1).

When the N-STaR recommendations were compared to Arkansas' standard N-rate recommendation of 150 lb N/ac for silt loam soils and 180 lb N/ac for clay soils, soil texture was found to be a significant factor ($P < 0.0002$), while county was not a significant factor. There were no increases in N-rate recommendations among the clay-textured soils submitted (Table 1). It should be noted that the validation of N-STaR on clay soils found no increased yield response to fertilizer rates above the standard N recommendation; therefore, N-STaR does not recommend N rates greater than 180 lb N/ac (Davidson et al., 2016). Of the 45 fields in this comparison, there was a decrease in N recommendation for 40 fields (89% of submitted fields) with an average decrease of 44.5 lb N/ac and an increase in recommendation for 5 fields (11% of those submitted and all on silt loam soils) with an average increase of 15 lb N/ac. N-STaR recommendations continue to be largely dependent on proper sampling depth for the respective soil texture and the correct soil textural classification of the field. Interestingly, increases in N rates were only observed in one county (Fig. 1).

Thirteen of the submitted fields had no estimated N rate specified on the N-STaR Sample Submission Sheet and were excluded from the comparison of the N-STaR recommendation to the producer's estimated N rate. Of the 32 fields that were compared, N-STaR recommended a decrease in N rate for all 32 fields with an average decrease of 34.9 lb N/ac (Table 2). Neither county nor soil texture was a significant factor in this comparison.

When the N-STaR recommendation was compared to the 2022 Recommended Nitrogen Rates and Distribution for Rice Cultivars, cultivar recommendations were adjusted for soil texture as recommended by adding 30 lb N/ac for rice grown on clay soils and then compared to the N rates determined by N-STaR. One field failed to include cultivar on the N-STaR Sample Submission Sheet and was therefore excluded from this comparison. There was a decrease in the N recommendation for 39 fields (89% of the 44 fields) with an average decrease of 43.1 lb N/ac (Table 3). Five silt loam fields (11% of compared fields) had an average increase in N recommendation of 15 lb N/ac. Soil texture was a significant factor ($P < 0.0008$) in this comparison with increases in N-rates recommended only for silt loam fields.

In all 3 comparisons, N-STaR proposed decreases as high as 97 lb N/ac. Decreases of 30 lb N/ac or greater were proposed in 76%, 63%, and 77% of fields evaluated in the standard, estimated, and cultivar rate comparisons, respectively. Alternatively, the greatest N-STaR recommended-N rate increase was only 15 lb N/ac in both the standard and cultivar comparison.

Practical Applications

Despite low sample submission numbers, these results continue to show the value of the N-STaR program to Arkansas producers and can help target areas of the state that would most likely benefit from its incorporation. Standard recommendations and cultivar recommendations will continue to be good starting points for N recommendations, but field-specific N rates continue to offer the best estimate of needed N, regardless of soil texture or cultivar selection. By using a field-specific N rate, farmers could see sizable fertilizer cost savings as future fertilizer-N costs rise while simultaneously decreasing possible negative environmental impacts as concerns intensify to protect the sensitive Mississippi watershed. Discussions with producers have suggested that they are using samples submitted from a single field to make management decisions for anywhere from 100–500 acres. Additionally, farmers have suggested that they are using N-STaR rate recommendations for 5–10 years. These 2 observations indicate that the true impact of the N-STaR program is hard to measure based on annual sample submissions. Farmers are encouraged to consider taking N-STaR samples at the harvest of the previous crop when fields are typically in optimal conditions for soil sampling and time for sampling is more likely. Sample submissions are expected to increase as fertilizer costs continue to cycle upward and farmers are aware of the potential cost savings possible with N-STaR sampling.

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Table 1. Distribution and change in nitrogen (N) fertilizer rate compared to the standard recommendation, producer's estimated N rate, and the 2022 Recommended Nitrogen Rates and Distribution for Rice Cultivars based on soil texture. [a]

		Decreased N-STaR Recommendation		Increased N-STaR Recommendation		
Soil Texture	Number of Fields Submitted	Number of Fields	Mean N Decrease (lb N/ac)	Number of Fields	Mean N Increase (lb N/ac)	No Change in Recommendation
Standard Soil Texture						
Clay	19	19	53.2	-	-	-
Silt Loam	26	21	36.7	5	15.0	-
Total	45	40	44.5	5	15.0	-
Producer Estimate						
Clay	17	17	36.0	-	-	-
Silt Loam	15	15	33.7	-	-	-
Total	32	32	34.9	-	-	-
Cultivar						
Clay	18	18	51.1	-	-	-
Silt Loam	26	21	36.0	5	15.0	-
Total	44	39	43.1	5	15.0	-

[a] Failure to include a producer's estimated N rate excluded 13 fields from the producer's estimate comparison. In the cultivar comparison, failure to list cultivar excluded 1 field.

Table 2. Distribution and change in nitrogen (N) rate compared to the producer's estimated N rate by county.[a]

County	Number of Fields Submitted	Decreased N-STaR Recommendation: Number of Fields	Decreased N-STaR Recommendation: Mean N Decrease	Increased N-STaR Recommendation: Number of Fields	Increased N-STaR Recommendation: Mean N Increase	No Change in Recommendation
			(lb N/ac)		(lb N/ac)	
Clay	11	11	24.1	-	-	-
Crittenden	1	1	97.0	-	-	-
Jefferson	1	1	30.0	-	-	-
Lawrence	4	4	63.8	-	-	-
Lonoke	23	11	36.8	-	-	-
Mississippi	1	1	25.0	-	-	-
Monroe	1	1	10.0	-	-	-
Woodruff	2	2	15.0	-	-	-
Total	45	32	34.9	-	-	-

[a] Thirteen fields were excluded from this analysis because no estimated N rate was listed on the N-STaR sample submission sheet.

Table 3. Distribution and change in nitrogen (N) rate compared to the 2022 Recommended Nitrogen Rates and Distribution for Rice Cultivars in Arkansas by cultivar.[a]

Cultivar	Number of Fields Submitted	Decreased N-STaR Recommendation: Number of Fields	Decreased N-STaR Recommendation: Mean N Decrease	Increased N-STaR Recommendation: Number of Fields	Increased N-STaR Recommendation: Mean N Increase	No Change in Recommendation
			(lb N/ac)		(lb N/ac)	
DG263L	3	3	33.3	-	-	-
Diamond	14	14	46.1	-	-	-
Jewel	1	1	55.0	-	-	-
PVL03	1	1	60.0	-	-	-
RT 7321 FP	2	2	57.5	-	-	-
RT 7521 FP	11	11	45.0	-	-	-
Titan	12	7	30	5	-15.0	-
Total	44	39	43.1	5	-15.0	-

[a] One field did not list a cultivar on the N-STaR sample submission sheet, so it was excluded from the analysis.

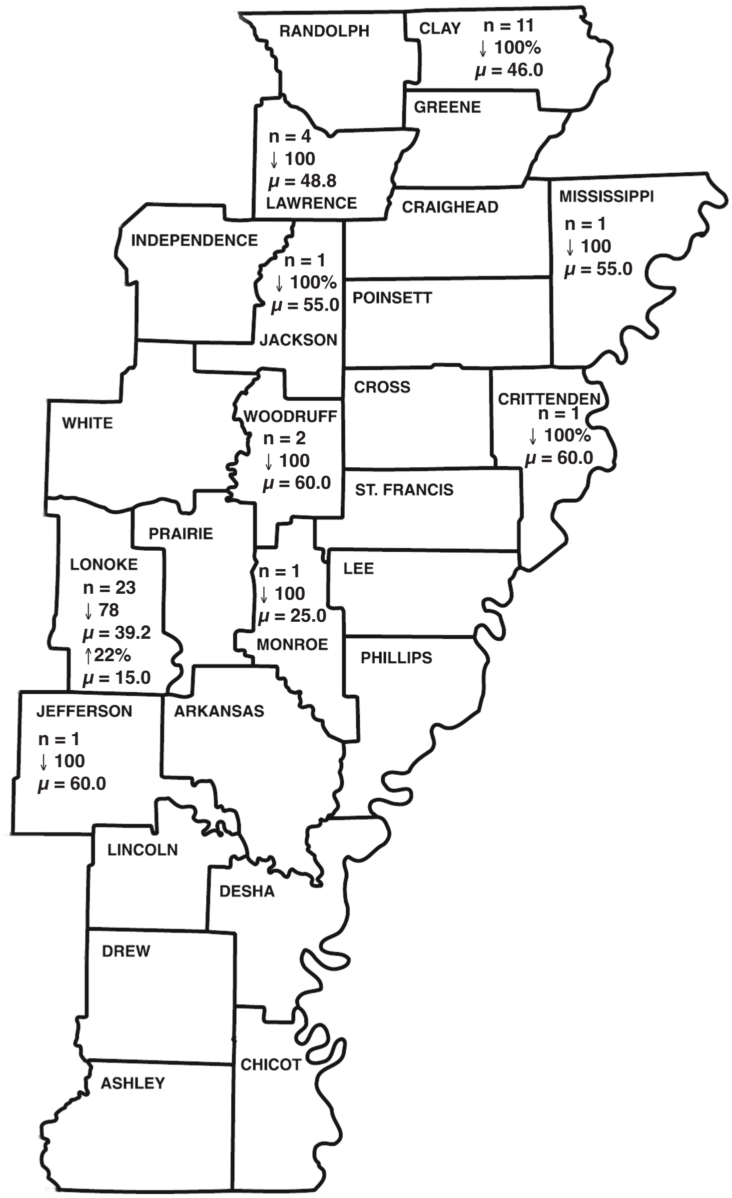

Fig. 1. Number of fields submitted, percent, and mean decrease and increase in N-STaR nitrogen (N) recommendation (lb N/ac) by county compared to the standard recommendation.

Influence of Seeding Rate on Performance of New Rice Cultivars

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Abstract

The rice cultivar by seeding rate study objective is to evaluate the response of new cultivars to selected seeding rates to determine the most effective seeding rate throughout the diversity of the rice-growing environmental conditions in Arkansas. These cultivars were seeded at 3 University of Arkansas System Division of Agriculture locations in Arkansas: the Rice Research and Extension Center (Stuttgart; silt loam soil), the Pine Tree Research Station (Colt; silt loam soil), and the Northeast Research and Extension Center (Keiser, clay soil). The pure-line varieties evaluated in 2022 were Ozark, Taurus, PVL03, DG263L, and RTv7231 MA seeded at 5, 10, 20, 30, and 40 seed/ft^2; and the hybrids evaluated were RT 7321 FP, RT 7331 MA, RT 7421 FP, and RT 7302 seeded at 4, 6, 8, 10, and 12 seed/ft^2. Results suggest that seeding rates lower than currently recommended are capable of producing optimal yields for the cultivars evaluated.

Introduction

The objective of this research is to correlate an efficient seeding rate for newly released rice cultivars throughout the different locations in Arkansas. There is a variety of additional factors such as planting date, seeding method, and seedbed preparation that could possibly increase the seeding rate recommendations from the ones recommended. The findings from this study will be used to refine seeding rate recommendations for Arkansas.

Procedures

Throughout this study, the pure-line varieties that were evaluated in 2022 are Ozark, Taurus, PVL03, DG263L, and RTv7231 MA seeded at 5 different rates: 5, 10, 20, 30 and 40 seed/ft^2. The hybrids evaluated were RT 7321 FP, RT 7331 MA, RT 7421 FP, and RT 7302 seeded at 5 different rates: 4, 6, 8, 10, and 12 seed/ft^2. Each of these cultivars is also tested across a wide variety of environmental conditions and different soil types. These cultivars were seeded at 3 University of Arkansas System Division of Agriculture locations in Arkansas: the Rice Research and Extension Center (RREC), Stuttgart, on a silt loam soil; the Pine Tree Research Station (PTRS), Colt, on a silt loam soil); and the Northeast Research and Extension Center (NEREC), Keiser, on a clay soil. Plots seeded were 8 rows (7.5-in. spacing) wide and 17.5 ft in length. The stand density of these rice cultivars was determined around the 3- to 4-leaf stage by counting the number of seedlings that have emerged on a 10 ft row throughout the plot. At harvest, the center 4 rows of each of these plots were harvested, and the moisture and grain yields were determined. Grain yield is adjusted to 12% grain moisture and reported in bushels per acre (bu./ac). These recommended practices for maximum yield were followed and the experimental design for all trials was a randomized complete block design with 5 replications. Statistical analysis was conducted using PROC GLM, SAS v. 9.4 (SAS Institute, Inc., Cary, N.C.) with means separation using Fisher's least significant difference test ($P = 0.05$).

Results and Discussion

At the RREC location, all varieties displayed a significant response to seeding rate for stand density (Table 1). Only PVL03 and RTv7231 MA had differences in grain yield as affected by seeding rate. For PVL03, the 10 and 20 seed/ft^2 rates produced yields higher than the 5 and 40 seed/ft^2 rates. For RTv7231 MA, the 10, 20, 30, and 40 seed/ft^2 rates resulted in higher yields compared to the 5 seed/ft^2 rate.

At the PTRS location, all varieties displayed a significant response to seeding rate for stand density (Table 2). Ozark, PVL03, and RTv7231 MA had differences in grain yield affected by seeding rate. For Ozark, the 20, 30, and 40 seed/ft^2 rates had higher yields compared to the 5 seed/ft^2 rate. For PVL03, the 20, 30 and 40 seed/ft^2 rates produced greater yields than the 5 seed/ft^2 rate; and the 40 seed/ft^2 rate also had higher yields than the 10 seed/ft^2 rate. For RTv7231 MA, the 10–40 seed/ft^2 rates had higher yields than the 5 seed/ft^2 rate.

At the NEREC location, all varieties again displayed a significant response to seeding rate for stand density (Table 3). No cultivars had significant yield response to seeding rate at this location.

At the RREC location, all hybrids displayed a significant response to seeding rate for stand density (Table 4). No cultivars had significant yield response to seeding rate at this location.

At the PTRS location, all hybrids displayed a significant response to seeding rate for stand density (Table 5). Only RT 7321 FP had a significant yield response, with the 12 seed/ft^2 rate resulting in higher yields compared to the 4 and 6 seed/ft^2

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rates. The 8 and 10 seed/ft^2 rates also had higher yields than the 4 seed/ft^2 rate.

At the NEREC location, all hybrids once again displayed a significant response to seeding rate for stand density (Table 6). RT 7421 FP had a response to grain yield with the 6, 8, and 12 seed/ft^2 rates producing higher yields than the 4 seed/ft^2 rate. RT 7331 MA seeded at 10 seed/ft^2 had higher yields than the 4 and 8 seed/ft^2 rates. The 6 and 12 seed/ft^2 rates also had higher yields compared to the 4 seed/ft^2 rate.

Results indicate that the currently recommended hybrid seeding rates can produce adequate stands to achieve optimal yields. However, results for varieties indicate that some varieties may achieve optimal yields at lower than currently recommended seeding rates. Additional analysis is needed to determine economically optimal seeding rates. It should be noted that all seed is treated with insecticide, fungicide, and bird repellent seed treatments to achieve and maintain maximum plant stands.

Practical Applications

For all cultivars, stand density increased significantly as seeding rate increased. For varieties, the 20 seed/ft^2 rate was needed to achieve minimum recommended stand densities, which is lower than the current recommended seeding rate. Similarly for hybrids, the 8 seed/ft^2 rate was needed to achieve minimum recommended stand densities, which is lower than the current recommended seeding rate. Grain yield response to seeding rate was variable. Multiple years of data are typically needed to refine grain yield response to seeding rate due to variability in stand density, particularly at low seeding rates.

The findings from this study will be used to refine seeding rate recommendations for Arkansas. The research results indicate that the currently recommended hybrid seeding rates can produce adequate stands to achieve optimal yields. However, results for varieties indicate that some varieties may achieve optimal yields at lower than currently recommended seeding rates to be efficient. The findings from this study are based on results from silt loam soils and currently recommended seeding rate adjustments based on soil type and seeding date.

Acknowledgments

The authors especially appreciate the cooperation of all participating rice producers who made this work possible. Funding for this project was provided through the rice. Check-Off funds administered by the Arkansas Rice Research and Promotion Board. We also appreciate the support from the University of Arkansas System Division of Agriculture for making this research possible.

Table 1. Influence of seeding rate on stand density and grain yield of selected varieties at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC).†

	Stand Density					Grain Yield				
Seeding Rate	DG263L	Ozark	PVL03	RTv7231MA	Taurus	DG263L	Ozark	PVL03	RTv7231MA	Taurus
(seed/ft^2)	(plants/ft^2)					(bu./ac)				
5	4.1 e‡	3.8 e	3.9 e	3.3 e	3.7 e	213.7	201.4	194.1 b	217.9 b	207.7
10	8.6 d	6.6 d	6.9 d	6.9 d	6.5 d	226.4	219.1	205.6 a	240.6 a	219.1
20	13.0 c	13.7 c	15.7 c	11.1 c	12.4 c	225.8	209.3	206.3 a	235.9 a	224.9
30	19.6 b	18.4 b	20.6 b	17.6 b	18.1 b	220.8	214.8	198.0 ab	236.4 a	217.7
40	28.5 a	23.3 a	25.6 a	20.9 a	24.6 a	224.7	217.2	193.6 b	231.9 a	220.1
$LSD_{0.05}$	<0.0001	<0.001	<0.0001	<0.0001	<0.001	0.5074	0.3983	0.0277	0.0120	0.1861

† Research station field near Stuttgart, Arkansas, on silt loam soil.

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

Table 2. Influence of seeding rate on stand density and grain yield of selected varieties at the University of Arkansas System Division of Agriculture's Pine Tree Research Station (PTRS).†

	Stand Density					Grain Yield				
Seeding Rate	DG263L	Ozark	PVL03	RTv7231MA	Taurus	DG263L	Ozark	PVL03	RTv7231MA	Taurus
(seed/ft^2)	(plants/ft^2)					(bu./ac)				
5	4.8 d‡	4.1 d	4.2 e	3.9 e	3.2 d	187.6	166.8 b	145.4 c	162.1 b	157.8
10	7.4 c	7.2 c	7.1 d	6.7 d	7.6 c	196.0	176.1 ab	158.4 b	178.4 a	170.8
20	13.2 b	12.4 b	14.1 c	12.4 c	11.6 b	191.8	182.1 a	166.9 ab	181.1 a	175.5
30	20.4 a	18.7 a	19.8 b	17.0 b	17.9 a	194.8	185.6 a	163.8 ab	181.2 a	162.5
40	19.2 ab	24.4 a	25.2 a	22.9 a	21.1 a	205.8	182.0 a	169.6 a	188.8 a	172.7
$LSD_{0.05}$	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.2130	0.0049	0.004	0.0466	0.1413

† Research station field near Colt, Arkansas, on silt loam soil.

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

Table 3. Influence of seeding rate on stand density and grain yield of selected varieties at the University of Arkansas System Division of Agriculture's Northeast Research and Extension Center (NEREC).[†]

	Stand Density					Grain Yield				
Seed Rate	**DG263L**	**Ozark**	**PVL03**	**RTv7231MA**	**Taurus**	**DG263L**	**Ozark**	**PVL03**	**RTv7231MA**	**Taurus**
(seed/ft²)	----------(plants/ft²)----------					----------(bu./ac)----------				
5	4.4 d[‡]	3.2 c	3.0 d	3.2 d	3.4 e	189.0	155.2	151.0	139.8	185.6
10	5.6 c	5.4 b	7.6 c	4.9 c	5.7 d	202.9	158.6	160.8	177.1	194.3
20	11.9 b	10.3 a	10.7 bc	8.3 b	9.5 c	182.2	172.9	155.3	188.2	202.7
30	16.0 a	13.0 a	12.4 b	12.1 a	14.3 b	162.3	157.2	157.7	180.5	188.7
40	16.0 a	12.7 a	19.9 a	15.8 a	17.4 a	183.7	166.7	157.8	187.9	192.7
$LSD_{0.05}$	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.1713	0.4025	0.5867	0.2360	0.5318

[†] Research station field near Keiser, Arkansas, on silt loam soil.

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

Table 4. Influence of seeding rate on stand density and grain yield of selected hybrids at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC).[†]

	Stand Density				Grain Yield			
Seed Rate	**RT7321FP**	**RT7421FP**	**RT7331MA**	**RT7302**	**RT7321FP**	**RT7421FP**	**RT7331MA**	**RT7302**
(seed/ft²)	----------(plants/ft²)----------				----------(bu./ac)----------			
4	2.5 c[‡]	3.1 d	2.8 d	3.5 d	214.7	210.6	232.0	237.9
6	4.6 b	4.4 c	4.9 c	5.7 c	226.0	213.6	252.4	245.3
8	5.0 b	5.4 b	6.4 b	7.0 bc	234.9	223.3	239.4	246.2
10	7.0 a	5.9 b	6.8 b	8.3 ab	229.1	233.9	239.6	254.1
12	6.9 a	8.5 a	9.4 a	9.9 a	237.2	226.7	249.3	249.7
$LSD_{0.05}$	<0.0001	<0.0001	<0.0001	<0.0001	0.0613	0.2810	0.5045	0.1816

[†] Research station field near Stuttgart, Arkansas, on silt loam soil.

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

Table 5. Influence of seeding rate on stand density and grain yield of selected hybrids at the University of Arkansas System Division of Agriculture's Pine Tree Research Station (PTRS).[†]

	Stand Density				Grain Yield			
Seed Rate	RT7321FP	RT7421FP	RT7331MA	RT7302	RT7321FP	RT7421FP	RT7331MA	RT7302
(seed/ft^2)	------------------------(plants/ft^2)------------------------				--------------------------(bu./ac)--------------------------			
4	2.9 c[‡]	3.1 d	3.5 c	3.4 d	169.5 c	180.4	192.4	201.0
6	5.5 b	3.8 c	5.0 b	5.4 c	177.8 bc	195.0	214.2	203.6
8	5.6 b	5.0 b	5.7 ab	5.9 c	193.0 ab	191.7	203.9	219.6
10	6.0 ab	6.0 ab	6.9 a	7.2 b	190.1 ab	192.5	213.2	218.0
12	7.3 a	7.0 a	7.6 a	8.8 a	202.8 a	202.7	217.8	202.5
$LSD_{0.05}$	<0.0001	<0.0001	<0.0001	<0.0001	0.014	0.1278	0.2213	0.3902

[†] Research station field near Colt, Arkansas, on silt loam soil.

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

Table 6. Influence of seeding rate on stand density and grain yield of selected hybrids at the University of Arkansas System Division of Agriculture's Northeast Research and Extension Center (NEREC).[†]

	Stand density				Grain Yield			
Seed Rate	RT7321FP	RT7421FP	RT7331MA	RT7302	RT7321FP	RT7421FP	RT7331MA	RT7302
(seed/ft^2)	------------------------(plants/ft^2)------------------------				---------------------------(bu./ac)---------------------------			
4	2.5 c	2.6 c	2.6 c	3.0 d	181.2	186.7 b	183.4 c	196.4
6	3.4 b	3.5 b	3.6 b	4.2 c	180.7	204.8 a	210.0 ab	198.9
8	4.3 a	3.5 b	5.9 a	5.3 bc	192.0	201.8 a	197.0 bc	205.7
10	4.9 a	4.8 a	6.4 a	5.6 b	184.3	199.1 ab	212.0 a	202.8
12	5.1 a	5.8 a	7.6 a	7.3 a	190.0	205.9 a	206.6 ab	199.6
$LSD_{0.05}$	<0.0001	<0.0001	<0.0001	<0.0001	0.5973	0.0455	0.0027	0.5974

[†] Research station field near Keiser, Arkansas, on silt loam soil.

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

Instantization Of Parboiled Rice: Impact of Initial Moisture Content and Drying Technique on Quality

K. Luthra[1] *and G.G. Atungulu*[1]

Abstract

Consumers' need for quick-cooking and nutritious rice has increased production of parboiled instant rice. The parboiling process has proven to enhance the nutrition and milling yield of rice. Hot-air oven drying is considered as one of the efficient drying methods; however, the impacts of the rice's initial moisture content (MC) and that of the drying process post-cooking on the quality of parboiled instant rice are not well understood. Therefore, the objective of this study was to assess the impact of initial MC of rough rice and hot-air stepwise oven drying on the quality of parboiled instant rice. Medium-grain cultivar Titan (22.5% MC wet basis) and long-grain cultivar RT 7521 FP (19.8% MC wet basis) were used after being conditioned to 16% MC and 12.5% MC. After parboiling, the samples were dried using natural air (77 °F air temperature and 56% air relative humidity) to 12.5% MC to produce white rice (milled to SLC of 0.4%) and brown rice. Rice was then cooked in excess water and dried using natural air as a control and stepwise oven drying (12 min total with 3 min at each oven temperature in the order of 446 °F, 428 °F, 410 °F, and 392 °F). Instant rice quality parameters (rehydration and volume expansion ratio, and color-L* value) were analyzed. Long-grain cultivars had higher rehydration ratios and lower color-L* values than medium-grain cultivars. Stepwise oven-dried parboiled instant rice had a higher rehydration ratio than that dried using the control method of natural air. The highest MC levels (harvest) had the lowest rehydration ratios, which advocates for using lower MC rice to generate parboiled instant rice. The volume expansion ratio did not significantly differ for most of the studied factors and levels. More work needs to be done to include more quality parameters such as bulk density, texture, water activity, and protein content in order to increase the significance of trends discovered in this study.

Introduction

The demand for instant rice is increasing, which is attributed to the rising consumer demand for food products that are easy to cook. The COVID-19 pandemic has escalated the demand for readymade (ready-to-eat) food items as well. Parboiled instant rice demand has increased as well due to consumer's concerns about improving their eating habits. Parboiled rice, in general, has the potential to be considered as a product that is gluten-free, a good source of calcium, rich in fiber, rich in potassium, rich in vitamins (B-6), and a good meal for diabetic patients.

Parboiling can be defined as a hydrothermal rice processing method. It involves soaking, steaming, and drying rice kernels before milling (Elbert et al., 2001; Bruce et al., 2018). During this process, the rough rice is soaked in excess water to a final moisture content (MC) of 25–35% (Bhattacharya, 1985). The rice is then steamed at 212–266 °F for 10 to 15 minutes and dried to approximately 12.5% MC. A complete parboiling process gelatinizes starch, causing the starch to expand and fill the fractures in the rice kernel, which lead to a harder kernel that resists breakage during milling (Derycke et al.; 2005; Elbert et al., 2001).

Instantization of rice involves cooking the rice completely and then drying it back to 12.5% MC. Parboiled instant rice is cooked and then dried back to produce the parboiled instant brown or white rice. The process of cooking the parboiled instant rice involves the shortest cooking time, i.e., 6 min for cooking milled and 12 to 15 min for cooking brown instant parboiled rice, respectively. It also has the advantage of producing plump kernels upon rehydration. Parboiled instant rice tends to absorb less water than regular instant rice. Also, the nutritional quality of instant parboiled rice shows that proteins are higher than the nutritional quality of regular rice proteins and similar to or higher than proteins from other cereals but lower than animal proteins, legumes, and oil seed proteins (Bruce et al., 2018).

The common drying process used in the industry for instant rice is hot-air drying. Not much research has been done to explain the impact of these drying techniques on the quality of parboiled instant rice. Also, several newer rice varieties are being produced, and the variable harvest moisture content can impact the quality as well; thus, there is a research gap. To address this gap, the objectives of this study were to investigate: (1) the impact of the initial moisture content of rough rice on the quality attributes of instant parboiled rice and (2) the impact of stepwise oven drying on the quality characteristics of instant parboiled rice.

Procedures

Sample Procurement

Medium-grain rice cultivar Titan (harvested at 22.5% wet basis) and long-grain hybrid rice RT 7521 FP (harvested at 19.8% wet basis) were gathered from rice farms in Northeast Arkansas. The samples were cleaned using dockage equipment (XT4, Carter-

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Day, Minneapolis, Minn., U.S.A). Each cultivar was conditioned to 16% MC, then 12.5% MC to generate approximately 22 lb at every moisture level. An equilibrium MC chamber (77 °F air temperature and 56% air relative humidity) was used to condition the rice. MC readings were taken frequently using a single kernel moisture content meter (CTR-800A, Shizuoka Seiki Co, Japan) to make sure the MC does not drop below the desired level. All moisture contents were reported on a wet basis. Rice was then stored in a walk-in cooler at 39 °F until the sample was used for experiments. When the rice was removed from the cooler, it was allowed to equilibrate for 24 hours in an airtight bag.

Experimental Design

Four factors, including rice cultivar (long-grain RT 7521 FP and medium-grain Titan), rice type (white and brown), moisture content (harvest-19.8% for RT 7521 FP and 22.5% for Titan, 16%, and 12.5% wet basis), and drying techniques (natural air drying-control and stepwise hot-air oven drying) were studied. Response variables were the parboiled instant rice quality parameters, including rehydration ratio, volume expansion ratio, and color. Three replications were used to avoid any manual error and biases in the results.

Experimental Procedures

A total of 17.6 lb of rice was measured and parboiled at each MC level. After parboiling, the samples were dried in an equilibrium MC chamber (77 °F and 56% relative humidity) to a milling MC of 12.5%. The dried samples were dehulled using a dehuller (THU35A, Satake Engineering, Tokyo, Japan) and then milled using a laboratory mill (McGill Number 2, Rapsco, Brookshire, Texas, USA) for 40 sec and 65 sec for Titan and RT 7521 FP, respectively to achieve a surface lipid content of 0.4%. The separation of the head rice from the brokens was done using a grain sieve shaker (RX-29, RO-TAP, Mentor, Ohio). Around 0.44 lb of head white and brown parboiled rice was cooked in excess water. Finally, the samples were independently dried using the control drying technique, i.e., natural air in an equilibrium MC chamber. The stepwise drying consisted of drying cooked parboiled instant rice at a starting temperature of 446 ºF. After 3 minutes in the first step, the temperature gradually reduced by 18 ºF, and the rice was held for 3 minutes before the temperature reduced again. Four steps or temperatures were used (446 ºF, 428 ºF, 410 ºF, and 392 ºF) for a total of 12 min, with 3 min at each temperature level. The airflow rate and air relative humidity were set at 11.2 ft/s and 60%, respectively. Samples that did not attain the required moisture content of 12.5% were further dried in the equilibrium moisture content chamber set at a temperature of 77 °F and 56% RH. Rehydration ratio, volume expansion ratio, and color were measured after parboiled rice instantization, as described in the following sections.

Rehydration Ratio Determination

The rehydration ratio of parboiled instant rice was determined by the method described by Prasert and Suwannaporn (2009) with slight modifications. Exactly 0.022 lb of dry instant rice with 3.4 oz water added was boiled for 6 min. The excess water was drained for 5 min, and the rehydrated instant rice was weighed. The rehydration ratio was calculated as the ratio of the weight of instant rice after hydration to the weight of instant rice before hydration, as shown in Eq. 1. The higher the rehydration ratio, the better the consumer acceptance.

$$Rehydration\ ratio = \frac{Weight\ of\ instant\ rice\ after\ rehydration\ (lb)}{Weight\ of\ instant\ rice\ before\ rehydration\ (lb)} \qquad \text{Eq. (1)}$$

Volume Expansion Ratio Determination

The volume expansion ratio was determined using the toluene displacement method. Exactly 0.018 lb of dry instant rice and rehydrated instant rice each were poured separately into a measuring cylinder containing 1.01 oz of toluene. The difference between the final volume and the initial volume was the volume of the rice sample. The volume expansion was then calculated as mentioned in Eq. 2 below. The higher the volume expansion ratio, the better the consumer acceptance.

$$Volume\ expansion\ ratio = \frac{Volume\ of\ rehydrated\ instant\ rice\ (oz)}{Volume\ of\ dry\ instant\ rice\ (oz)} \qquad \text{Eq. (2)}$$

Color Determination

The International Commission on Illumination (CIE) color parameters (L*/a*/b*) were determined using Near-Infrared (NIR) spectrometer with a diode array analyzer (DA 7200, Perten instruments, SE-141 05 Huddinge, Sweden). Samples were held in a spinning sample cup while the NIR spectrum was collected. The color parameter L* value, which indicates the overall whiteness of the samples was used in this study. L* value ranges from 0 (pure black) to 100 (pure white). The higher the value of L*, the more the rice samples are preferred by consumers.

Statistical Analyses

Analysis of variance and Student's *t*-test were performed using statistical software JMP Pro 17 (SAS Institute, Inc., Cary, N.C.) to determine the statistical significance of each factor on the response variables and significant differences between mean values of the responses for factor levels, respectively. The level of significance was set at 5% for mean comparison.

Results and Discussion

Effect of Cultivars on Rehydration Ratio, Volume Expansion Ratio, and Color of Parboiled Instant Rice

Table 1 shows that long-grain and medium-grain cultivars used in this study did significantly impact the rehydration ratio and color of the parboiled instant rice. However, no changes in the volume expansion ratio were observed. Long-grain cultivar (RT 7521 FP) had a higher rehydration ratio (2.08) and color L* value (31.97) (the higher the better) than that of the medium-grain cultivar (2.02-rehydration ratio and 31.02-color) (Table 2).

Effect of Drying Technique on Rehydration Ratio, Volume Expansion Ratio, and Color of Parboiled Instant Rice

The two drying techniques studied (natural air drying and hot-air stepwise oven drying) were compared for the quality parameters of the parboiled instant rice. The drying techniques did significantly impact the rehydration ratio (*P*-value of <0.0001), volume expansion ratio (*P*-value of 0.0107), and the color (*P*-value of 0.0084) of the parboiled instant rice. Hot-air stepwise oven-dried parboiled instant rice had a higher rehydration ratio (2.10) than that dried using natural air (2.00) (Table 2).

Effect of Different Types of Rice (White or Brown) on Rehydration Ratio, Volume Expansion Ratio, and Color of Parboiled Instant Rice

White and brown parboiled instant rice had statistically different rehydration ratios and colors (Table 1). However, no changes in the volume expansion ratio were observed. White parboiled instant rice had a higher rehydration ratio of 2.17 as compared to that of brown rice (1.92), which means the white parboiled instant rice will elongate more after cooking as compared to brown. Due to the bran layer on parboiled instant brown rice, it had a lower L* color value than white parboiled instant rice (Table 2).

Effect of Moisture Content on Rehydration Ratio, Volume Expansion Ratio, and Color of Parboiled Instant Rice

There were statistical differences observed in terms of rehydration ratio and color for parboiled instant rice that had different initial moisture levels (Table 1). However, no changes in the volume expansion ratio were observed. The minimum rehydration ratio of 2.00 was observed for the highest moisture content level (at harvest). And, at 16% and 12.5% MC, the rehydration ratio of the parboiled instant rice was the same as 2.07.

Practical Applications

Compared to the medium-grain cultivar, the long-grain cultivar evaluated had a greater rehydration ratio and color value, which will be more popular. Parboiled instant rice that was hot-air stepwise oven-dried had a higher rehydration ratio than rice dried using the standard method of employing natural air. The lowest rehydration ratio was found for rice with the highest MC level (harvest), which points to the use of lower MC rice to produce parboiled instant rice. Except for the drying technique, no other factors had any significant differences in the volume expansion ratio. The main purpose of this research was to use and apply science-based knowledge to give the industry a broad understanding of how the quality attributes of instant parboiled rice can be impacted by rice harvest moisture contents and conventional drying processes, including natural air drying and hot-air stepwise oven drying. More work needs to be done to include more quality parameters for improving the significance of the trends found in this study.

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Table 1. The *P*-value based on the analysis of variance to depict the statistical significance of the factors across the responses (α = 0.05).

	Response variables†		
Factors	**Rehydration ratio**	**Volume expansion ratio**	**Color (L* value)**
Cultivar	0.0346	0.1931	0.0005
Drying technique	<0.0001	0.0107	0.0084
Rice type	<0.0001	0.1439	<0.0001
Moisture content	0.0223	0.1484	<0.0001
Replication	0.8271	0.3581	0.5282

† The *P*-value <0.05 depicts the statistical significance of the factor on the response variable.

Table 2. The mean value of response variables is categorized into various levels of each factor studied.

		Response variables†		
Factors	**Levels**	**Rehydration ratio**	**Volume expansion ratio**	**Color (L* value)**
Cultivar	RT 7521 FP	2.08 a	1.03 a	31.97 a
	Titan	2.02 b	1.02 a	31.02 b
Drying technique	Natural air drying	2.00 b	1.04 b	31.14 b
	Oven + Natural air drying	2.10 a	1.02 a	31.85 a
Rice type	White	2.17 c	1.03 a	39.49 c
	Brown	1.92 d	1.02 a	23.50 d
Moisture content	Harvest	2.00 b	1.02 a	30.49 e
	16%	2.07 a	1.03 a	30.06 f
	12.5%	2.07 a	1.03 a	31.94 a
Replication	1	2.06 a	1.03 a	31.29 b
	2	2.05 a	1.03 a	31.56 ab
	3	2.04 a	1.03 a	31.64 ab

† Means followed by the same letter in the same column are not significantly different at *P* = 0.05.

Impacts of Drying Conditions on Rice Fissuring and Seed Germination

S.O. Olaoni,[1] K. Luthra,[1] and G.G. Atungulu[1]

Abstract

Freshly harvested long–grain rice cultivar with a moisture content of 16.5% w.b. (wet basis) was used during the experiments. The rough rice samples were dried as thin layers at temperatures of 86 °F, 104 °F, and 122 °F, with constant air relative humidity (RH) of 50% and air velocities (AV) of 2.17 ft/s and 5.41 ft/s. X-ray imaging was used for fissure detection before and after drying the samples to a moisture content of 13.5% w.b. Following drying, the samples were subjected to seed germination tests, with the experimental runs done in triplicates. Results from fissure analysis showed that fissure intensity increased with a rise in temperature from 86 °F–122 °F for high and low AV, respectively, with more intensity observed at 5.41 ft/s. For seed germination (SG), it was observed that drying treatment at 122 °F and 2.17 ft/s demonstrated the highest germination rate of 94%. Furthermore, there was no correlation between fissure intensity and seed germination based on the drying conditions applied in this study. Overall, this study provided new insight and baseline information on the seed germination of rice. These data will be useful in designing a more comprehensive experiment for conditions encountered in the industry.

Introduction

Rice (*Oryza sativa* L.) is a semiaquatic plant cultivated in at least 95 countries around the globe and used as a staple food for more than half of the world's population (Coats, 2003). According to Mukhopadhyay and Siebenmorgen (2017), rice is typically harvested at a high moisture content (MC) between 18–24% wet basis as rough rice and must be dried immediately to approximately 13% MC soon after harvest for safe storage. In the United States, about 60% of the produced rough rice is used for direct consumption, more than 20% is used for processed food, approximately 15% for the brewing industry as beer, and the remaining nearly 5% is used as seeds. Since seeds are the most vital component of the grain, especially in ensuring its supply for plantations, they must be properly dried and kept at a safe moisture content to mitigate the rate of microbial activity and the development of insects, which affect the seed quality.

Inter-kernel MC differences during storage and/or transportation, as well as improper drying of kernels, lead to stress cracks (fissures) in the seeds (Schluterman and Siebenmorgen, 2007). Cnossen and Siebenmorgen (2000) proposed an explanation for the cause of fissure formation during the drying process based on hygroscopic property imbalances caused by state transitions inside kernels. These fissures are fractures of the endosperm that are either perpendicular to the long axis of the kernel or in random alignment and can damage the integrity of these seeds (Kunze and Calderwood, 2004). Seed viability or germinability is defined as the ability of the seed to germinate and produce normal seedlings under suitable conditions (Van De Venter, 2001). High temperatures can damage cell membranes, inactivate enzymes, degrade storage proteins, and split the seed coat, resulting in the formation of fissures and decreasing seed viability.

Several publications detailed seed germination (SG) studies for some grains, including corn, wheat, and soybean. Regardless, there is insufficient data on the impact of various air conditions, such as relative humidity (RH) and air velocities (AV), on rice seed germination. Hence, the objective of this research was to determine the impact of drying rice seed at three temperature levels (86 °F, 104 °F, and 122 °F), two AV (2.17 ft/s and 5.41 ft/s), and 50% RH on rice fissuring and seed germination.

Procedures

Rice Sample

Long grain hybrid rice cultivar (RT 7521 FP) harvested at the initial moisture content (IMC) of 16.5% (wet basis) at Lepanto, Arkansas, in September 2021 were used in this study. The samples were cleaned and stored in the walk-in cooler at 39.2 °F before the experiment. Before the experiment, samples were removed from the cooler and allowed to equilibrate for 24 h, after which the moisture content (MC) was determined to be 15.5 ± 0.1% (w.b) using the oven drying method (Jindal and Siebenmorgen, 1987). Samples needed for the experiment were passed through a precision sizer (ABE2, Carter-Day Co., Minneapolis, Minn.) with a long grain screen size (0.08 in) for 5 mins to ensure consistency and uniformity of kernel sizes.

Drying of Samples

Six 0.132-lb subsamples were obtained from individual triplicates to represent each experimental run. 0.092 lb of each rough rice sample was separated for the drying experiment, while the remaining 0.040 lb (30% of the 0.132 lb) was used for pre–fissuring analysis. Samples with less than three layers based on rice

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thickness were fully exposed to the drying air stream and dried to 13.5% (w.b) as thin-layer dryings (ASABE standard, 2014). The sample was placed on a 10 in × 10 in perforated wooden wire–meshed tray and dried using air temperatures of 86 °F, 104 °F, and 122 °F with constant RH of 50% and AVs of 2.17 ft/s and 5.41 ft/s using a setup designed by Prakash and Siebenmorgen (2018). This setup was modified to accommodate automated grain weight measurement and insulated to avoid condensation at the current experimental conditions. The drying air conditions were produced by a 32.84 ft^3 controlled environmental chamber (ESL 4CA Platinous Temperature and Humidity Chamber, Espec, Hudsonville, Mich.) with an inline centrifugal fan (FG-4, Fantech, Lenexa, Kans.) mounted outside the chamber to avoid exposure to high temperature. Immediately after drying, samples were allowed to cool in an equilibrium moisture chamber (77 °F, 56% RH) for 15 mins, then placed in sealed plastic bags for further analysis. Rough rice samples that were not dried were considered control samples for each replicate.

X-ray Imaging

Thirty percent of the dried sample were exposed to post–fissuring analysis using the X-ray system (UltraFocus 60, Faxitron Bioptics LLC, Tucson, Ariz.) seen in Fig. 1, while the remaining portion was kept for germination experiments. Fissures were enumerated by placing 50 rough rice kernels on an acrylic glass sheet within the system, as images were scanned and generated by the X-ray system using a magnification of 2.0. Fissures intensities were quantified using Eq. 1 defined below.

$$\text{Fissure Intensity (\%)} = \frac{\text{number of fissured kernels}}{\text{total number of kernels} - \text{immature or damaged kernels}} \times 100 \qquad \text{Eq. (1)}$$

The fissure percentage for each treatment was calculated by subtracting the fissure intensities obtained during the pre-fissuring and post-fissuring analysis.

Germination Experiment

Four hundred kernels picked from the lots of dried samples separated for germination experiment were germinated for each replication. The rice kernels were placed on a 0.029 lb/ft^2 regular-weight, brown germination paper (Anchor Paper Co, Saint Paul, Minn.). The germination paper was laid out using the methods described by the Arkansas State Plant Board, with one sheet of germination paper on the bottom, a second page on top of the initial sheet where the seeds were placed, and a top sheet covering the seeds (ADA, 2020). Each batch consisting of four rolls was placed in an individual plastic bag and stored in an incubating chamber (Binder BF, Tuttlingen, Germany) at 68 °F for 16 h/day in light conditions and 86 °F for 8 h/day in dark conditions to mimic real-life growing environment (AOSA, 2016). After 14 days, a germination assessment was carried out on each rolled sample using the germination criteria based on the official seed analysts' rules for long-grain rice germination (AOSA, 2009). Kernels that have all the parts of a plant (i.e., roots, shoots, and leaves present with no malformations or missing parts) were considered germinated. The germination percentage of each treatment was expressed using Eq. 2, as seen below.

$$\text{Seed Germination (SG\%)} = \frac{\text{total number of germinated seeds}}{\text{total number of seeds}} \times 100 \qquad \text{Eq. (2)}$$

Statistical Analyses

Statistical analyses were conducted using JMP Pro statistical software v. 16.2 (SAS Institute, Inc., Cary, N.C.). The analyses were conducted to determine the variables with the greatest impact on fissure intensity and seed germination. A completely randomized full factorial analysis (CRD) was conducted in triplicates. Relationships between the control samples and other treatments were visualized, while significant differences between means of individual treatments were established using Student's *t*-test procedure (least significant difference $P > 0.05$).

Results and Discussion

Impact of Temperature and Air Velocity on Fissure Intensity

Figure 2 shows the graphical representation of the main effect (temperature and air velocity) on the fissure intensity of the kernel. It can be observed that an increase in temperature from 86 °F to 122 °F leads to a rise in fissure intensity for both AVs, with more intensity occurring at 122 °F. Table 1 shows the analysis of variance (ANOVA) results of temperature and air velocity on the two responses (fissure intensity and seed germination). From the statistical analysis, it was observed that, within the bounds of the experimental design conditions, there was no significant interaction between temperature and AV; likewise, AV has no significant effect on fissure intensity, while there is a borderline significant effect of temperature on fissure intensity with a *P*-value of 0.056. Table 2 provides values for fissure intensities at different temperatures and AVs, and it can be observed that fissure intensity increased from 1.46% at 86 °F to 3.07% at 122 °F for air velocity of 2.17 ft/s, with a similar trend observed at 5.41 ft/s as the intensity increased from 1.44% to 3.80% for 86 °F and 122 °F, respectively. Siebenmorgen et al. (2005) discovered that for samples dried in thin layers in a large chamber controlled at 69.8 °F and 60% RH, the percentage of fissured kernels, when using a grainscope, for Cypress, Drew, and Wells was 1.0%, 1.5%, and 1.5%, respectively. This demonstrated that fissure intensities differ between cultivars, and though fissure intensity was not significantly different at 50% RH for this cultivar and within the temperature and AV ranges observed in this study, the difference of <2% is very important to note.

Impact of Temperature and Air Velocity on Seed Germination

Table 2 shows the seed germination percentage of the rice seeds across the temperature range and AVs, with all treatments having a SG greater than 90%. Figure 3 shows the relationship between the averages of the control and treatments at each temperature level while considering both AVs. It was observed that seed germination for the control sample was relatively similar to that of seeds dried at 86 °F and relatively lower than that of seeds dried at 104 °F and 122 °F. From Figure 4, which shows the seed germination for both AVs, a parallel trend was observed, with germination increasing rapidly from 86 °F to 104 °F then slightly to 122 °F, with the best germination occurring at 122 °F at 2.17 ft/s air velocity. Wang et al. (2017) found that drying rice seeds in a single layer (0.12–0.20 in.) at two drying temperatures (122 °F and 140 °F) with RH of 5.6% and 4.2%, respectively, for durations of 5–20 minutes had an adverse effect on seed germination. However, this study found that this is not the case since temperature and AV have no significant effect on seed germination (Table 1). It is important to note that the study by Wang et al. (2017) used very low RHs compared to our study.

Practical Applications

This study investigated the impacts of temperature and air velocity (AV) on rice fissuring intensity and seed germination at 50% constant RH. The study used X-ray imaging to identify and quantify fissures in rice kernels while providing new insight in terms of the impact of temperature on seed germination after drying. It was noticed that at 50% RH, seeds germinated at 86–122 °F were not significantly different from each other, indicating that drying at a relatively high temperature of 104 °F does not have an effect on the germination of the seeds. Furthermore, for the studied experimental conditions, fissure intensity had no direct impact on seed germination. Finally, the percentage points difference between the highest and lowest treatment in terms of fissuring intensity (≈2%) and seed germination (≈ 3.5%) data is practically significant in helping seed companies to minimize drying impact on the seed.

Acknowledgments

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Table 1. Analysis of variance of the factors across the responses (α = 0.05).

Factors	Fissure Intensity	Seed Germination
	P-Value	*P*-Value
Temperature	0.056	0.093
Air Velocity	0.193	0.238

Table 2. The fissure intensities and seed germination percentages of each treatment at different temperatures and air velocities (AV).

AV	Temperature	Fissure Intensity	Seed Germination
(ft/s)	(°F)	(%)	(%)
2.17	86	1.46	92
	104	1.62	94
	122	3.07	95
5.41	86	1.44	91
	104	3.38	93
	122	3.80	94
Control (No drying)			92

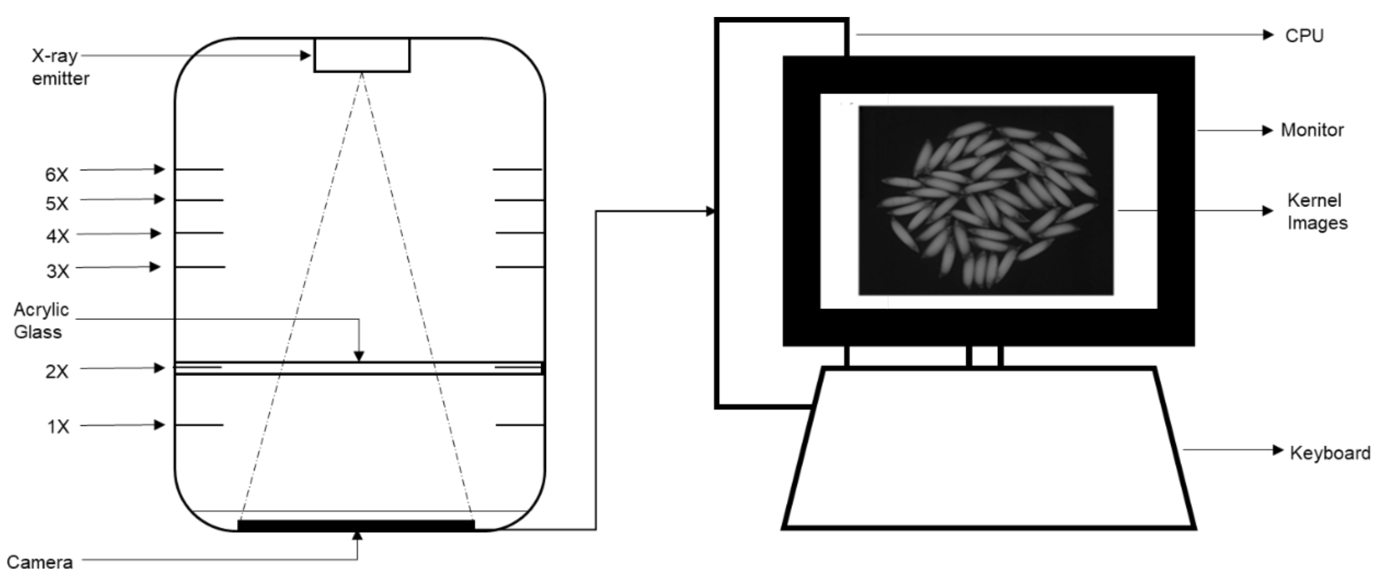

Fig. 1. A schematic diagram of the X-ray system showing the generated sample image with 50 kernels at a magnification of 2.0.

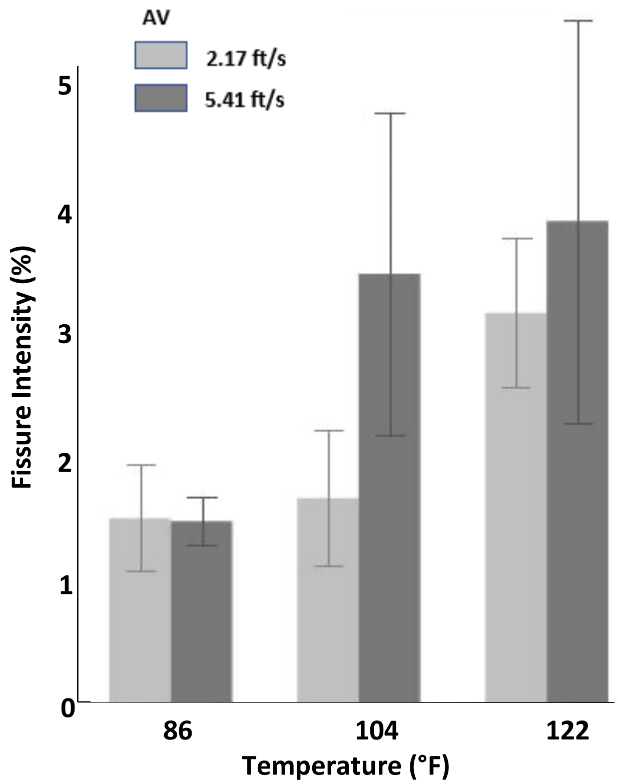

Fig. 2. Impact of temperature and air velocity (AV) on fissure intensity.

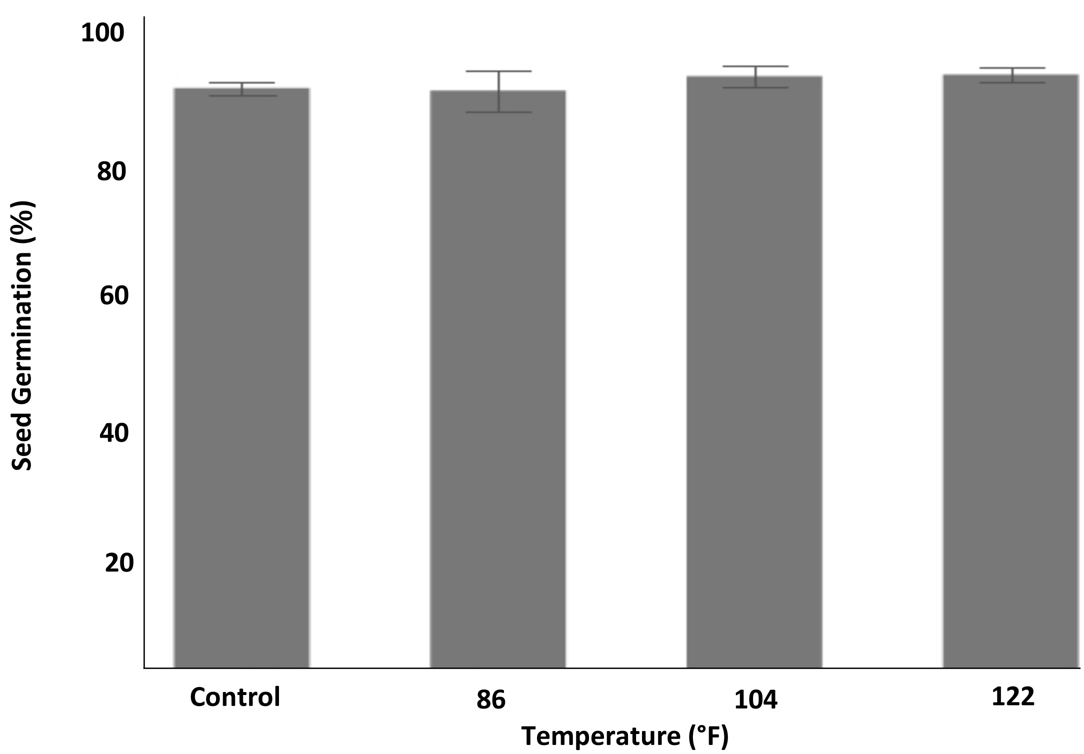

Fig. 3. Impact of temperature on seed germination with control. Each bar represents the means of each treatment.

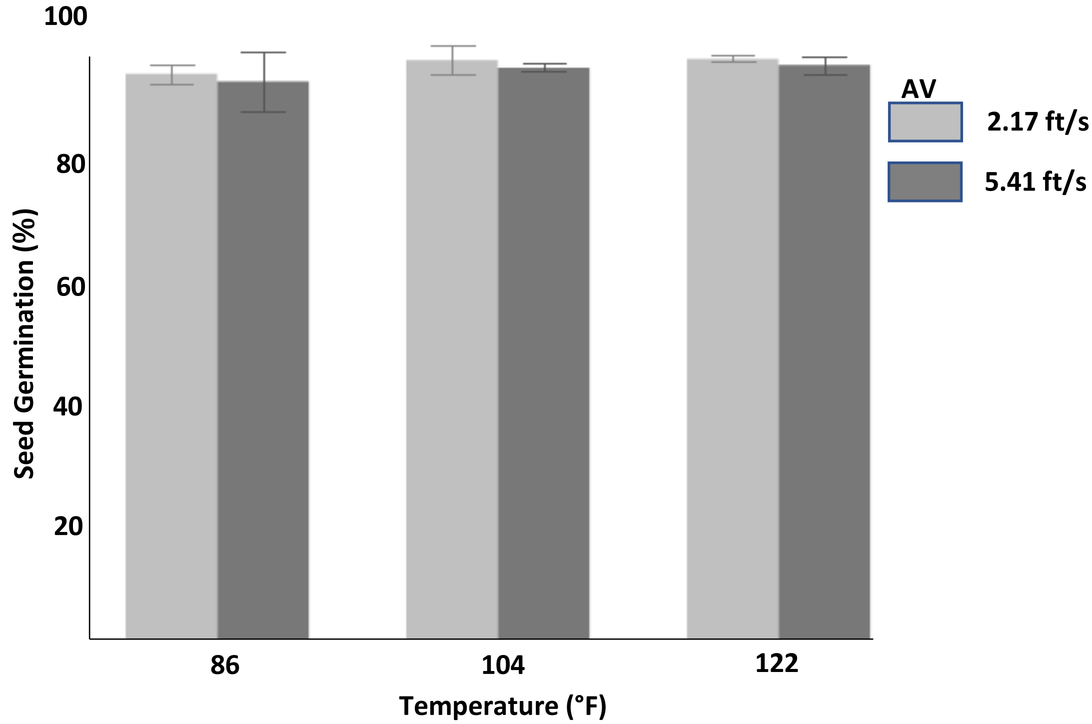

Fig. 4. Impact of temperature and air velocity (AV) on seed germination.

Rice Material State Diagrams: Trends of Contemporary Cultivars

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Abstract

Improper drying of rice causes kernel fissuring, which leads to head rice reduction and significant economic losses to growers. Prediction of kernel fissuring during active drying and tempering is vital for controlling the rice drying process. The glass transition theory has been developed by the University of Arkansas System Division of Agriculture's Rice Processing Program as a tool to help explain fissuring incidences in rice during drying. The glass transition temperature (T_g) defines the point that the rice material transits from glassy to rubbery states and vice versa. Presently, the drying and tempering temperatures used in the industry are informed by material state diagrams defined by T_g points that were determined for old pure-line rice cultivars. These diagrams may be insufficient for controlling the proper drying of recently developed pure-line and hybrid rice. Therefore, the objective of this study was to generate material state diagrams with updated T_g for contemporary pure-line and hybrid rice cultivars. Samples of 7 different rough rice cultivars harvested in 2022 were conditioned to moisture contents (MC) levels of 20%, 18%, 16%, 14%, and 12% wet basis. A differential scanning calorimeter was used to determine the T_g of the rice samples at the various MC levels. In the analysis, sections of the rice samples were equilibrated to –86 °F and then heated from –86 to 482 °F at a rate of 41 °F/min. The average T_g for the rice samples determined at 20% MC was 102.2 °F, 105.8 °F at 18% MC, 109.4 °F at 16% MC, 113 °F at 14% MC, and 116.6 °F at 12% MC. Material state diagrams were developed from these new data. These diagrams showed higher Tg values and improved model accuracy ($R^2 = 0.88$) in comparison to that of earlier studies and can be utilized by rice growers to ensure that drying activities are carried out at temperatures that will not lead to kernel fissuring.

Introduction

Rice kernels with internal fractures within the endosperm are commonly referred to as fissured kernels. These fissures tend to break during milling, and this leads to significant reductions in milling yields. The functional properties of fissured rice kernels are also immensely affected after their milling, which causes significant financial losses to the end-use processors (Siebenmorgen et al., 2009). It is, therefore, imperative to minimize kernel fissuring formation in the rice industry by understanding how these fissures tend to occur during the active drying of rice.

The glass transition temperature (T_g) is an important parameter that represents the temperature range where rice starch changes from a hard glassy phase to a soft rubbery phase. This concept has been applied to identify the role of intra-kernel material state differences that cause fissures to form in rice kernels. According to Cnossen and Siebenmorgen (2000), fissuring of a rice kernel may be attributed to the differential stress within the kernel exceeding the kernel material strength. Per the literature, these differential stresses are developed when sufficient portions of the kernel periphery transition to a glassy state while the kernel core remains in a rubbery state during drying.

According to the glass transition theory, fissuring of rice kernels can occur in two scenarios during drying. The first hypothesis stipulates that as the temperature of a rice kernel approaches the drying air temperature during high-temperature drying, the condition of the grain changes from a glassy to a rubbery state. Over time, the surface layers of the kernel lose moisture at a more rapid rate than the core of the kernel. In this instance, the surface layers with lower moisture content (MC) due to the drying may transition back to the glassy state. This theory suggests that in situations when drying is extended such that ample portions of the kernel periphery transition to a glassy state while the core remains in a rubbery state, extreme conditions of intra-kernel material state gradients occur between the surface and the core areas. This, therefore, results in stresses which can exceed the kernel material strength, causing fissures to start occurring (Cnossen and Siebenmorgen, 2000). The second scenario where fissuring is hypothesized to occur is when cooling is done right after drying without sufficient tempering (a process of holding rice at the drying temperature for some duration). During active drying, intra-kernel material state and MC gradients are created but may not be enough to cause fissuring. However, if these existing gradients after drying are not allowed to subside and the kernel is immediately cooled, the kernel surface and core will transition to the glassy state at different instances. This, as a result, creates severe intra-kernel material state gradients that could cause fissuring (Cnossen and Siebenmorgen, 2000).

It is hypothesized that when the tempering temperature is below the T_g of the rice, the kernel will undergo a further glass transition into the glassy state as the kernel temperature decreases, and this causes fissuring to occur (Cnossen and Siebenmorgen, 2000). Using the Tg of rice, material state diagrams can be developed to predict the material states (glassy/rubbery) of rice kernels or por-

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tions of kernels at given temperatures and moisture contents. The data from these material state diagrams, therefore, informs the rice industry on the appropriate drying and tempering temperatures to employ for drying rice kernels after their harvest. However, the present drying and tempering temperatures utilized are informed by material state diagrams of old pure-line rice cultivars (Bengal and Cypress) harvested in 1997 (Perdon et al., 2000). These diagrams may be insufficient for describing the drying behaviors of contemporary pure-line and hybrid grain cultivars. It is hence vital to develop new material state diagrams for these contemporary cultivars. The objective of this study seeks to generate material state diagrams for contemporary pure-line and hybrid rice cultivars.

Procedures

Sample Procurement and Preparation

Rough rice of high moisture content of seven different cultivars was harvested from rice plots in Harrisburg, Ark., in 2022. Five of these cultivars were sampled from two distinct plots totaling 12 samples. The rough rice samples were cleaned using a dockage tester (XT4, Carter-Day, Minn., USA). A precision sizer (ABF2, Carter-Day Company, Minneapolis, Minn.) was used to grade the thickness of the rough rice samples to achieve uniformity in kernels and reduce variation in samples used during the experiment. The cleaned and size fractioned rough rice samples were conditioned to 12% moisture content (wet basis) using gentle natural air drying (77°F air temperature, 56% air relative humidity). During the drying process, the moisture contents of the rough rice samples were measured to obtain rice samples at 20%, 18%, 16%, 14%, and 12% (wet basis). This was achieved by measuring the rice samples in triplicates using the moisture content meter (AM 5200–A, PerkinElmer, Hagersten, Sweden). Brown rice samples were obtained by hand dehulling the hulls from the rough rice samples. The samples of brown rice obtained at various MC levels were then kept in sealed plastic tubes and stored at 39.2 °F before further analysis. Figure 1 also describes the methodology as a flowchart.

Differential Scanning Calorimetry (DSC) Analysis

The glass transition temperatures of samples at various MC levels were determined using a differential scanning calorimeter (Diamond DSC, Perkin Elmer, Shelton, Conn.). In the DSC analysis, sections of the individual brown rice kernels were used. Each kernel was cross-sectioned into two parts using a razor blade. The sectioned kernels were placed inside the equipment's high-pressure stainless-steel pan and carefully sealed with a pan cover for each analysis. The DSC system was then set to equilibrate the sectioned brown rice samples to –86 °F and then heated from –86 to 482 °F at a rate of 41 °F/min. The T_g from each thermogram was then determined by identifying the transition corresponding to a slope change in the heat capacity of the sample.

Statistical Analysis

A simple linear regression test was conducted on the data from the experiments using JMP Pro 17 statistical software JMP Pro 17 (SAS Institute, Inc., Cary, N.C.). The level of significance for the analysis was set at a 95% confidence level.

Results and Discussion

Material state diagrams for the distinct cultivars as well as a combined diagram for all the cultivar types were developed. Figures 2, 3, and 4 show material state diagrams for medium-grain (Jupiter), aromatic long-grain pure-line (ARoma 22), and non-aromatic long-grain pure-lines (Diamond, PVL03, and CLL16), as well as long-grain hybrids (V3503 and XP 784), respectively. The material state diagram for all contemporary rice cultivars explored in this study is shown in Fig. 5.

From the material state diagrams, a strong, negatively correlated linear relationship existed between the MC and the T_g. The T_g of the rice kernels increased with decreasing moisture content. This was similar to trends observed in studies by Perdon et al. (2000) and Sun et al. (2002). The T_g vs. MC relationship obtained from the contemporary rice cultivars (hybrid long-grain, pure-line long-grain, and medium-grain) explored in this study (Fig. 5) can be represented by a regression function as in equation 1.

$$T_g = 140.12 - 1.928\ MC,\quad R^2 = 0.88 \qquad \text{Eq. (1)}$$

From previous studies, the combined material state relationship developed for Bengal and Cypress cultivars by Perdon et al. (2000) is also reported by equation 2:

$$T_g = 134.74 - 1.950\ MC,\quad R^2 = 0.53 \qquad \text{Eq. (2)}$$

The T_g values obtained from the contemporary cultivars explored in the study were higher compared to that from previous studies. There was also a higher R^2 value, explaining about 88% of variations in the new model. The T_g of brown rice at typical harvest MC of 20% from this study is approximately 102.2 °F, which is slightly higher compared to that of the previous study at approximately 96.8 °F. The T_g of the medium-grain pure-line cultivar (Jupiter), as depicted by the regression equations (Fig. 2), also showed slightly higher T_g values as compared to the long-grain cultivars. The T_g values for long-grain pure-lines (Fig. 3) also had slightly lower values compared to the T_g values of the combined long-grain hybrid cultivars (Fig. 4).

Practical Applications

These results can be used to predict the transition states (glassy/rubbery) of rice kernels at given temperatures and MCs. According to this study's equation (1), using rice for drying and tempering at temperatures lower than the projected T_g (102.2 °F) at a typical harvest MC (20%) will probably cause a further transition of the kernel material state, which may result in the rice kernel fissuring. These data become very handy to rice growers by ensuring that the drying and tempering operations are carried out at required temperatures and durations that would not result in defects like the fissuring of rice kernels.

Acknowledgments

Arkansas Rice Processing Program and the University of Arkansas System Division of Agriculture are immensely appreciated for their support and facilities. Special thanks to RiceTec for sample acquisition, Dr. Ya-Jane Wang of the Food Science Department, and all members of Dr. Griffiths Atungulu's lab for their kind guidance and service in this research.

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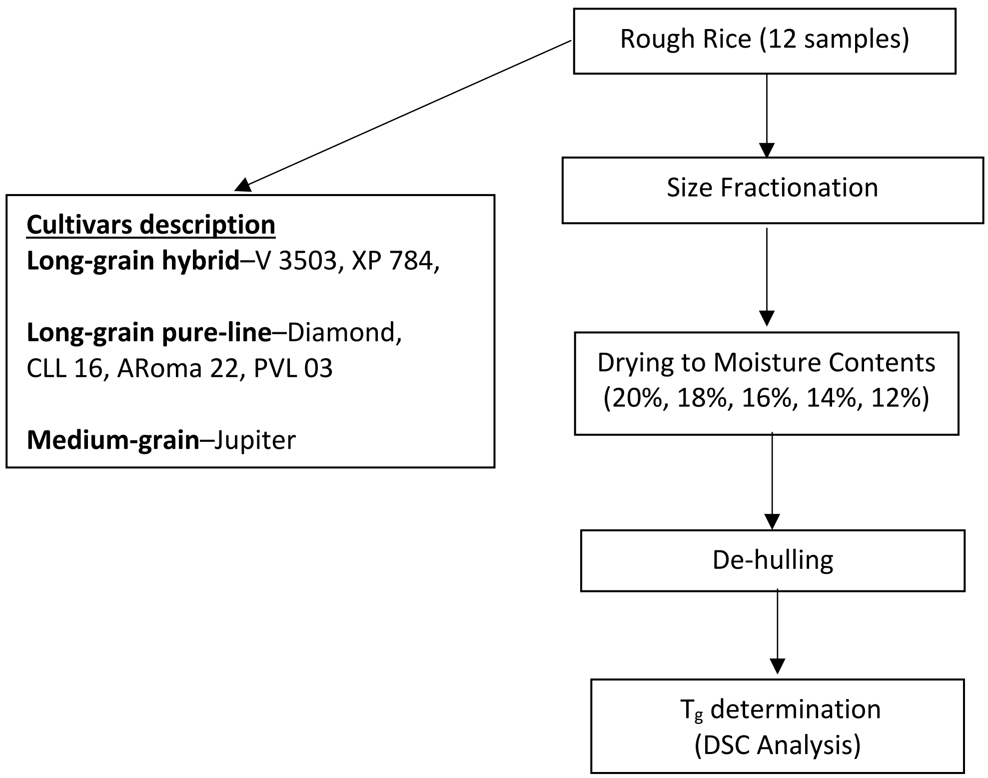

Fig. 1. Experimental flowchart.

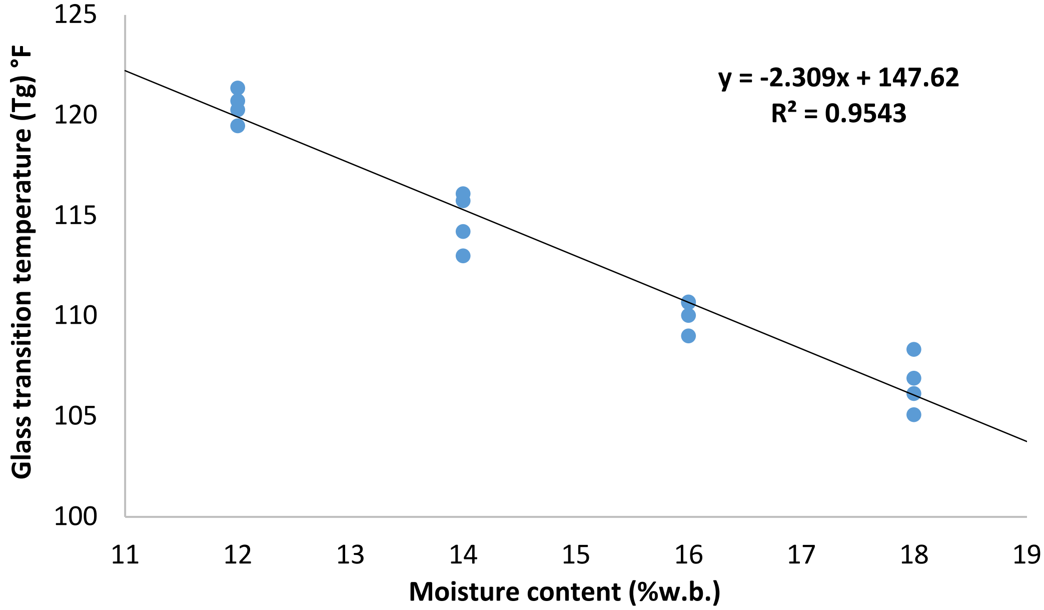

Fig. 2. Material state diagram for medium-grain rice (Jupiter).

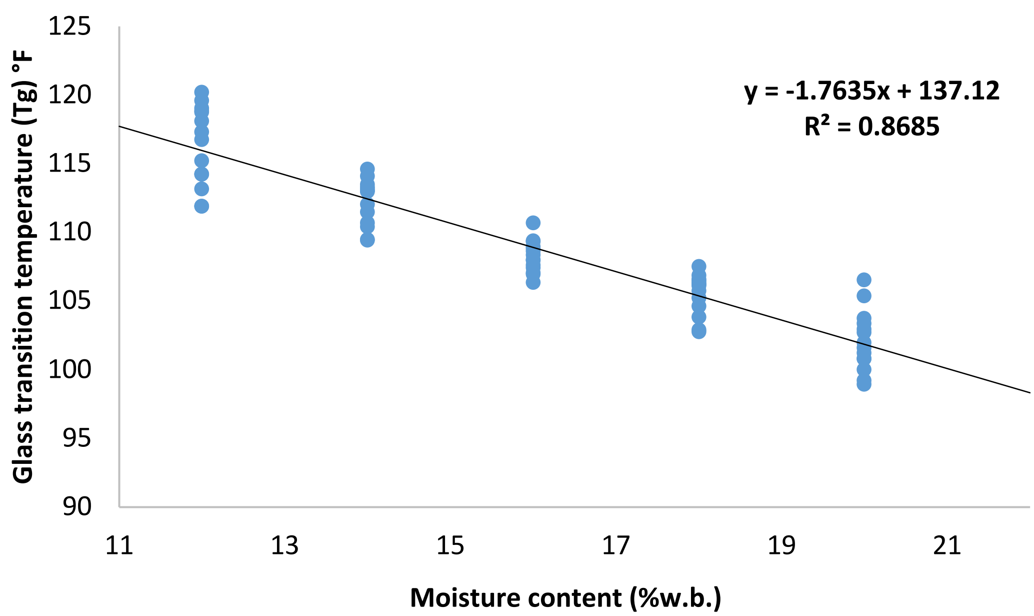

Fig. 3. Material state diagram for long-grain pure line rice (ARoma 22).

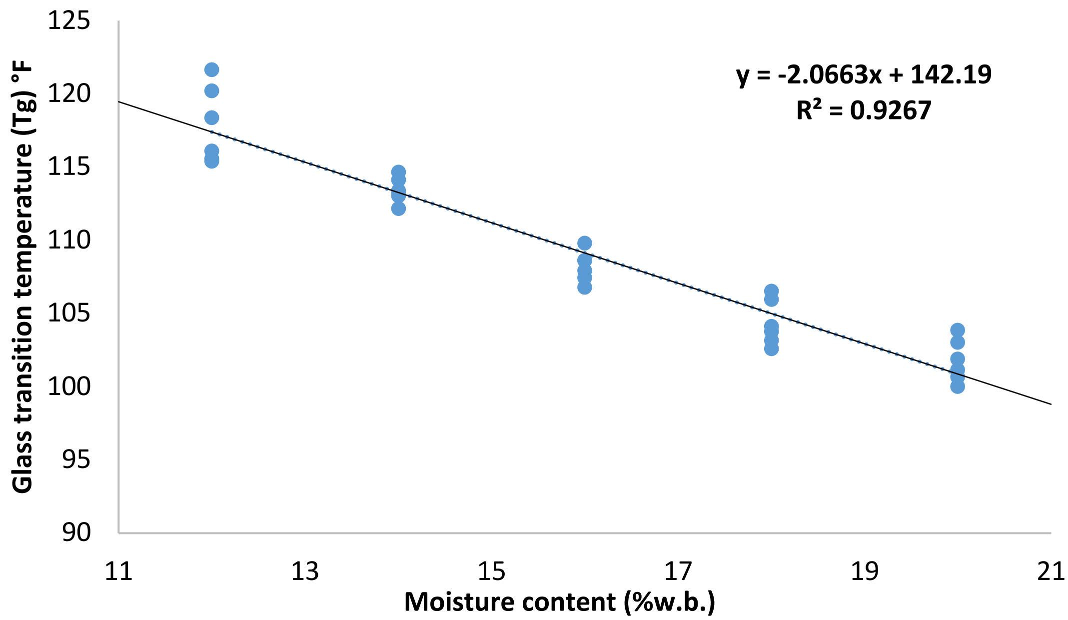

Fig. 4. Combined material state diagram for long-grain hybrid rice (Diamond, V3503, XP 784, CLL16, PVL03).

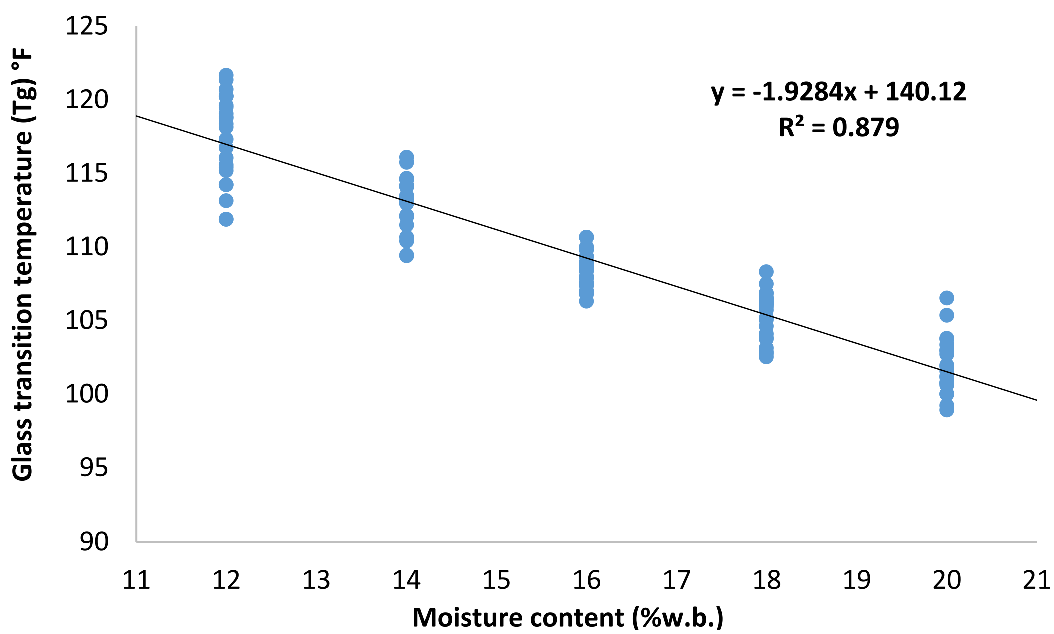

Fig. 5. Combined material state diagram for contemporary rice (Diamond, V3503, XP 784, CLL16, PVL03, ARoma 22, Jupiter).

World and U.S. Rice Baseline Outlook, 2022–2032

A. Durand-Morat[1] *and S.K. Bairagi*[1]

Abstract

The marketing year 2021 marked a record of global rice production, consumption, and trade. Despite the good production performance, the global rice market was deficient as consumption surpassed production for the first time since 2004. Rice prices from most origins and rice types in 2021 decreased slightly but still remained at relatively high levels compared to their levels pre-COVID. Relative to their level in 2019–2021 level, the international (free on board or FOB) price of long-grain rice, represented by Thailand 100% B rice, is projected to increase on average by 0.9% annually, while the international price of medium-grain rice, represented by U.S. No.2 from California, is projected to grow by 1.4% annually over the next decade. World rice production and consumption are projected to expand by a cumulative 6.7% and 7.6%, respectively, over the next decade, with India experiencing the largest expansion in both areas. Global rice trade is projected to increase significantly and reach 62 mmt by the end of the projected period.

Introduction

According to the USDA, global rice production reached back-to-back record highs of 509 and 515 million metric tons (mmt) in 2020 and 2021, driven primarily by record production levels in India and good performances in China, Bangladesh, and Thailand. At the same time, global consumption has been growing steadily and reaching new records every year but experienced a significant increase in 2021 when it reached 518 mmt relative to 499 the year before. For the first time since 2004, the global rice market was deficient (consumption surpassed production) in 2021.

Despite the tightening of the global rice market, prices did not increase markedly and actually decreased for some particular types and origins. The FAO rice price index decreased for all categories (all rice, indica, aromatic, and glutinous) except the japonica price index (FAO, 2023), whose increase was driven primarily by the decrease in production in California. Looking at long-grain rice prices for major rice exporters, FAO (2023) reports a decrease in export prices out of Thailand (100% B) and Pakistan (5% broken) in 2021 relative to 2020, similar prices for India (5% broken), and slightly higher export prices for Vietnam (5% broken).

Global rice trade reached a record of 57 mmt or 11.2% of the global rice production in 2021. India dominated global rice exports with 22 mmt of rice exported, equivalent to a 39% market share. To put this in perspective, India exported the same amount as the other top-5 rice exporters (Thailand, Vietnam, Pakistan, and the U.S.) combined.

So far, the 2022 marketing year has seen a tighter situation due to the projected decrease in production in India and, to a lesser extent, China. The production of the main (Kharif) crop in India was down significantly due to drought-like conditions in many of the rice areas, but good rains in late Fall coupled with a higher guaranteed price of Indian rupees 20,400 ($259) per metric ton of paddy rice are expected to improve the production of the second (Rabi) crop. To counter the potential inflationary impact of a shorter-than-expected Kharif crop, the Government of India implemented an export tariff in September 2022, which has resulted in an increase in export prices out of India. It remains to be seen whether India will lift the export restrictions, which to a large extent, depends on the performance of the second (Rabi) crop.

Procedures

The baseline estimates presented in this report are generated using the Arkansas Global Rice Model (AGRM), a partial equilibrium, non-spatial, multi-country/regional statistical simulation and econometric framework developed and maintained by the Arkansas Global Rice Economics Program (AGREP) in the University of Arkansas System Division of Agriculture Department of Agricultural Economics and Agribusiness in Fayetteville, Ark. The AGRM model covers 70 countries and regions that produce and consume rice; and projects rice supply and demand as well as international and domestic rice prices up to 2031.

Most of the details, theoretical structure, and general equations of AGRM can be found in Wailes and Chavez (2011). The historical rice data come from USDA-FAS (2023a, 2023b) and USDA-ERS (2023). The macroeconomic data (e.g., gross domestic product, exchange rate, and population growth) come from S&P Global, provided by the Food and Agricultural Policy Research Institute (FAPRI)-Missouri.[2] The baseline projections are grounded in a series of assumptions as of January 2023 about the general economy, agricultural policies, weather, and technological change. The basic assumptions are a continuation of existing

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[2] FAPRI-Missouri is the lead institution of the research consortium that develops the annual baseline projections. It includes the University of Missouri-Columbia, the University of Nevada-Reno, the University of Arkansas in Fayetteville, Texas A&M University, and Texas Tech University.

policies, current macroeconomic variables, no new WTO trade reforms, and average normal weather conditions.

Results and Discussion[3]

Over the next decade, the international (free on board or FOB) price of long grain rice, represented by Thailand 100% B rice, is projected to increase on average 0.9% annually and average US$502/mt by 2030–2032 relative to US$455/mt observed in the last three years (2019–2021) (Fig. 1; Table 1). Similarly, the international price of medium-grain[4] rice, represented by U.S. No. 2 from California, is projected to grow 1.4% annually on average over the next decade and reach US$1172/mt in 2030–2032 relative to US$1002/mt in 2019–2021 (Fig. 1; Table 1). We project that the international price of long-grain rice will remain stable in the very short run and experience a small but steady increase thereafter as global supply increases to catch up with growing global demand. On the other hand, we project that the price of medium-grain rice will peak in 2022 due to a very short crop in California, but expected to ease in 2023 and 2024 as production goes back to more normal levels thanks to the increased availability of water. Medium-grain prices are projected to remain above US$1,100/mt over the projected period.

The price gap between U.S. and Thai long-grain rice is expected to remain high in 2022 (around US$300/mt) but decrease thereafter as production increases in the U.S. and demand for Thai and Asian rice remains strong. In the long run, the price gap will decrease but is likely to remain above US$160/mt, supported by the assumption that the U.S. will continue to enjoy market preference across core markets in Latin America vis-à-vis Asian rice markets. Additionally, the increasing competition from Mercosur, primarily Brazil, observed in recent years may plateau as excess supply in Brazil stabilizes. With that said, it seems that an increase in U.S. rice production must be accompanied by a decrease in prices to make it possible for the U.S. to regain some market share lost to Brazil and Uruguay in traditional core markets such as Mexico and Central America.

Global rice output is projected to continue expanding over the next decade, supported by the increasing adoption of modern varieties and other improved production technologies, in many cases as part of strategic self-sufficiency policies in developing countries across Asia and Africa. World rice production is projected to expand by 34 mmt or 6.7% over the next decade, reaching around 541.7 mmt in 2030–2032, led primarily by yield gains and a slight increase in area (Table 2; Fig. 2). India is projected to have the largest growth in production, accounting for around 23% of the production gain in the coming decade, followed by Thailand (11%), Bangladesh (10%), Vietnam (8%), and Indonesia (5%). In contrast, rice production is projected to decline in China (-1.4 mmt) and also in Japan, South Korea, and Taiwan. Total U.S. rice production is projected to increase marginally by 47 tmt or 0.7% over the same period (Table 3; Fig. 3).

Global rice consumption is projected to increase by 38.3 mmt, reaching 542 mmt on average in 2030–2032 (Table 2; Fig. 2). Over the next decade, world rice consumption will continue to be driven by population growth, as the global average per-capita rice consumption declines from 64.8 kg/person in 2019–2021 to 63.5 kg/person in 2030–2032. Rising incomes continue to dampen rice demand in some Asian countries such as Japan, Taiwan, China, and South Korea, where rice is considered an inferior good. Moreover, demographic trends such as decreasing and aging populations and increased health consciousness caused a shift in preferences away from carbohydrates and towards protein-based diets, which ultimately weakened rice demand in some countries.

India accounts for about 18% of the net growth in global rice consumption over the next decade. Regionally, West Africa, more specifically ECOWAS,[5] accounts for over a quarter of the projected consumption growth over the next decade. U.S. domestic rice use will increase by 409 tmt over the next decade, reaching an average of 7.2 mmt in 2030–2032 (Table 3; Fig. 3).

We project that global rice trade will expand by 11.9 mmt over the next decade and reach 62.4 mmt on average in 2030–2032 (Table 1; Fig. 2). On the export side, we project India will remain by far the largest exporter over the coming decade, supported by normal weather that will allow it to maintain a high level of production and excess supply. Likewise, we project Thailand to regain its position as the second-largest rice exporter surpassing Vietnam.

For the U.S., total exports over the next decade are expected to increase by 142 tmt, reaching 3.0 mmt a year in 2030–2032, while imports are to increase by 229 tmt, totaling 1.4 mmt a year in 2030–2032 (Fig. 3). For reference purposes, detailed U.S. rice supply and use data are presented in English units and on paddy basis (rough rice equivalent) in Table 3.

On the import side, China, West Africa, and the Philippines are expected to be the leading rice importers over the next decade. We project that China will remain the largest single rice importer and will likely expand its import reach across Asia and beyond the traditional suppliers (Vietnam and Myanmar). Nigeria's rice imports are expected to reach 3.4 mmt a year, while the Philippines is projected to expand imports to 3.6 mmt a year by 2030–2032.

Global rice stocks are projected to grow in the coming decade, reaching 195 mmt by the end of the projected period (Table 2; Fig. 2). However, global rice stocks are projected to decrease slightly relative to total consumption over the next decade, with the stock-to-consumption ratio projected to increase from 36.7% annual average in the period 2019–2021 to 36.0% in 2030–2032. In other words, annual ending stocks in 2030–2032 will be enough to feed the global population for 4.3 months.

[3] Although complete baseline projections for supply and demand variables are generated for all 70 countries/regions covered by AGRM, only selected variables for major countries are discussed in this report due to space considerations.

[4] In AGRM, medium-grain rice represents an aggregation of both medium- and short-grain rice.

[5] Benin, Burkina Faso, Cape Verde, Cote d'Ivoire, Gambia, Ghana, Guinea, Guinea-Bissau, Liberia, Mali, Niger, Nigeria, Senegal, Sierra Leone, and Togo.

Practical Applications

Understanding the market and policy forces that drive the global rice market is beneficial for Arkansas rice producers and other stakeholders. This ramification is especially true because Arkansas is the top rice-producing state in the U.S., accounting for nearly 51% and 57% of the country's total and long-grain rice production, respectively, in 2019–2021. Market prices received by Arkansas rice producers are primarily determined by the dynamics of the international rice market. This outlook can serve as a baseline reference for further policy scenario analysis and is intended for government agencies and officials, farmers, consumers, agribusinesses, and other stakeholders.

Acknowledgments

This material is based upon work supported in part with funding provided by the rice producers of Arkansas through the rice check-off funds administered by the Arkansas Rice Research and Promotion Board. The authors thank the University of Arkansas System Division of Agriculture for its support. We greatly appreciate the Arkansas rice farmers' support through the Rice Research and Promotion Board, which provided part of the funding for the annual development, update, and maintenance of the Arkansas Global Rice Model. The model was updated 3 times in 2022 and once in January 2023 in collaboration with FAPRI-Missouri, which provided the major portion of the funds for the global rice modeling program of AGREP.

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Table 1. Projected changes in world rice total trade by country (in 1,000 metric tons) with U.S. and global prices.

Country	2019–2021 Average	2030–2032 Average	Change	Country	2019–2021 Average	2030–2032 Average	Change
Exporters							
India	18,254	21,717	3,464	EU 28	462	546	84
Thailand	6,633	9,445	2,813	Australia	109	448	339
Vietnam	6,546	8,378	1,832	Peru	40	27	-13
Pakistan	4,166	4,116	-50	Guinea	87	80	-7
United States	2,856	2,998	142	Cote d'Ivoire	35	30	-5
Myanmar	2,167	3,436	1,269	Egypt	10	5	-5
China	2,300	3,256	955	Japan	86	120	34
Cambodia	1,633	2,245	611	Turkey	235	230	-5
Brazil	1,156	900	-256	Tanzania	102	125	23
Uruguay	867	906	40	Venezuela	0	0	0
Paraguay	721	881	160	Senegal	67	140	73
Guyana	490	554	64	Sri Lanka	7	8	1
Argentina	382	389	7	Laos	-67	-50	17
				Rest of world	1,138	1,440	302
Total Exports					**50,482**	**62,371**	**11,889**
Importers							
China	4,255	4,029	-226	Canada	456	458	2
Nigeria	2,017	3,433	1,416	Sierra Leone	407	327	-79
Ecowas 7[a]	2,277	4,248	1,971	Egypt	381	670	289
Philippines	2,750	3,631	881	Liberia	317	498	181
EU 28	2,074	2,531	457	Sri Lanka	282	-42	-324
Cote d'Ivoire	1,332	2,546	1,214	Hong Kong	304	360	56
Saudi Arabia	1,371	1,692	321	Peru	257	339	81
Iran	1,107	1,635	528	Singapore	381	352	-30
Bangladesh	907	876	-30	Turkey	428	391	-37
Iraq	1,367	1,827	460	Tanzania	147	174	27
Senegal	1,217	1,870	653	Thailand	192	171	-21
South Africa	993	1,106	113	Mali	467	936	470
Indonesia	650	756	106	Australia	246	239	-7
Malaysia	1,190	1,067	-123	Chile	175	177	2
United States	1,156	1,385	229	Costa Rica	159	153	-7
Mexico	788	896	108	Colombia	153	222	69
Ghana	920	1,298	378	Honduras	147	249	101
Guinea	790	787	-3	Uganda	83	194	111
Japan	682	685	3	Taiwan	104	100	-4
Brazil	793	507	-286	Guatemala	125	166	41
Kenya	625	1,197	572	Nicaragua	95	153	58
Mozambique	650	1,059	409	Panama	62	114	52
Cameroon	592	793	201	Brunei	24	29	5
Cuba	412	509	97	Rwanda	40	173	133
Haiti	490	601	111	Dominican Republic	24	19	-5
Vietnam	1,233	1,000	-233	Malawi	15	62	47
Venezuela	588	802	214	Zambia	10	60	50
South Korea	440	421	-19	Pakistan	6	6	0
Madagascar	541	1,022	481	Paraguay	1	0	-1
				Rest of world	10,790	11,416	626
Total Imports					**50,482**	**62,371**	**11,889**
Prices (US$/metric ton)							
Long grain International Rice Reference Price (Thailand 100% B)					455	502	48
U.S. No. 2 long grain FOB[b] Gulf Ports					639	670	31
U.S. No. 1 medium grain FOB California					1,002	1,172	170

[a] Includes the following seven members of the Economic Community of West African States: Benin, Burkina Faso, Gambia, Guinea-Bissau, Niger, Togo, Cape Verde.

[b] FOB = free on board.

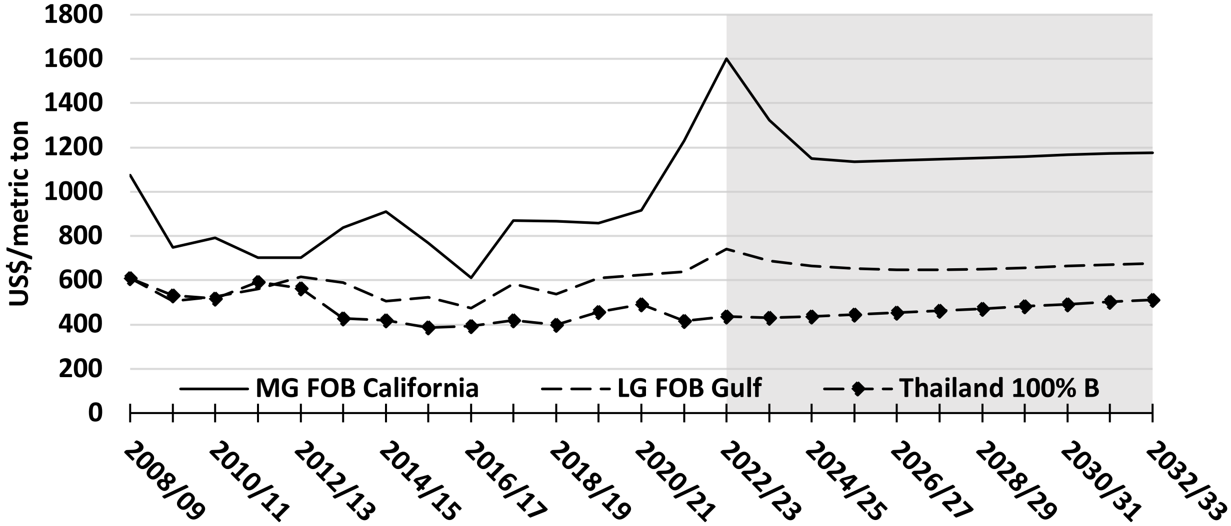
Table 2. Projected world rice supply and utilization (in 1,000 metric tons) and macroeconomic data.

Variable	2019–2021 Average	2030–2032 Average	Change
Area Harvested (1,000 ha)	164,334	166,024	1,690
Yield (kg/ha)	3.09	3.26	0.17
Production	507,741	541,743	34,002
Beginning Stocks	182,751	194,008	11,257
Domestic Supply	690,491	735,751	45,260
Consumption	503,239	541,553	38,314
Ending Stocks	184,615	195,137	10,522
Domestic Use	687,853	736,690	48,836
Total Trade	50,482	62,371	11,889
Stocks-to-consumption Ratio (%)	36.69	36.03	-0.66
Annual population growth (%)	0.9	0.8	-0.1
Annual real GDP[a] growth (%)	1.3	2.6	1.3

[a] GDP = Gross domestic product

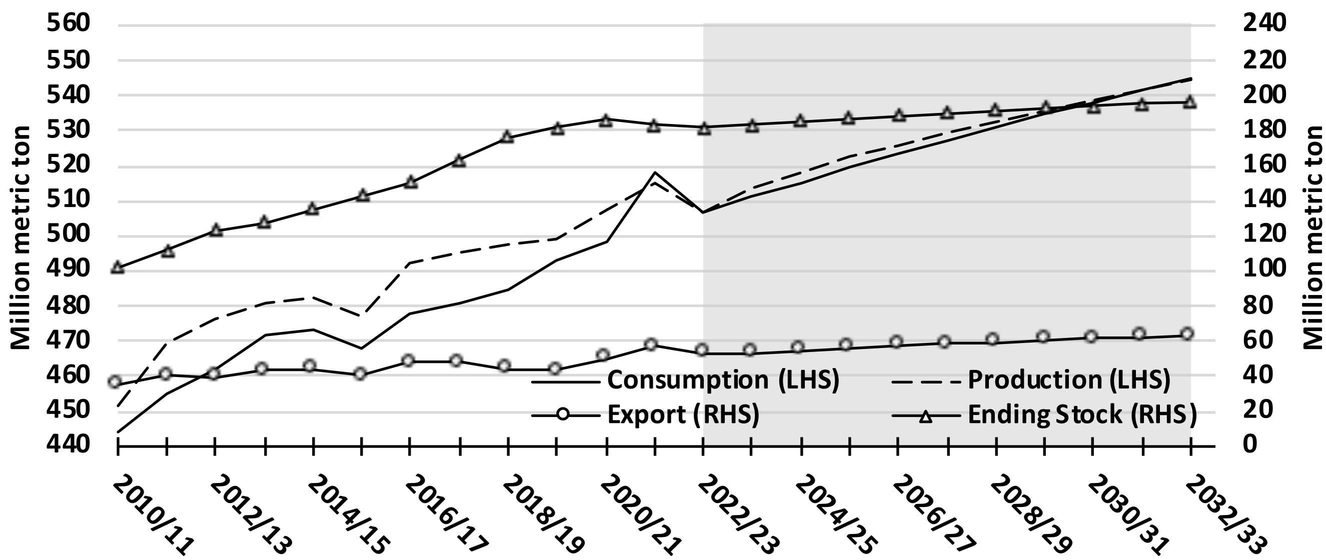
Table 3. United States rice supply and utilization (in paddy basis, million hundredweight unless specified otherwise) and prices.

Variable	2019–2021 Average	2030–2032 Average	Change
Yield (lb/ac, paddy basis)	7,603.5	8,204.7	601.2
Total Harvested Area (1,000 ac)	2,649.3	2,557.8	-91.5
Supply	275.1	293.3	18.2
Production	201.5	209.9	8.4
Beginning Stocks	37.2	39.8	2.6
Imports	36.4	43.6	7.2
Domestic Use	149.6	158.6	9.0
Exports	90.0	94.4	4.5
Total Use	239.5	253.0	13.5
Ending Stocks	35.5	40.3	4.8
Stocks-to-Use Ratio	0.15	0.16	0.01
		Market Prices (US$/cwt)	
Loan Rate	7	7	0
Season Average Farm Price	14.7	16.4	1.74
Long-Grain Farm Price	12.7	14.4	1.67
Medium-Grain Farm Price	21.0	23.0	1.97
Japonica Farm Price	24.2	26.3	2.11
Southern Medium-Grain Farm Price	12.8	14.6	1.78



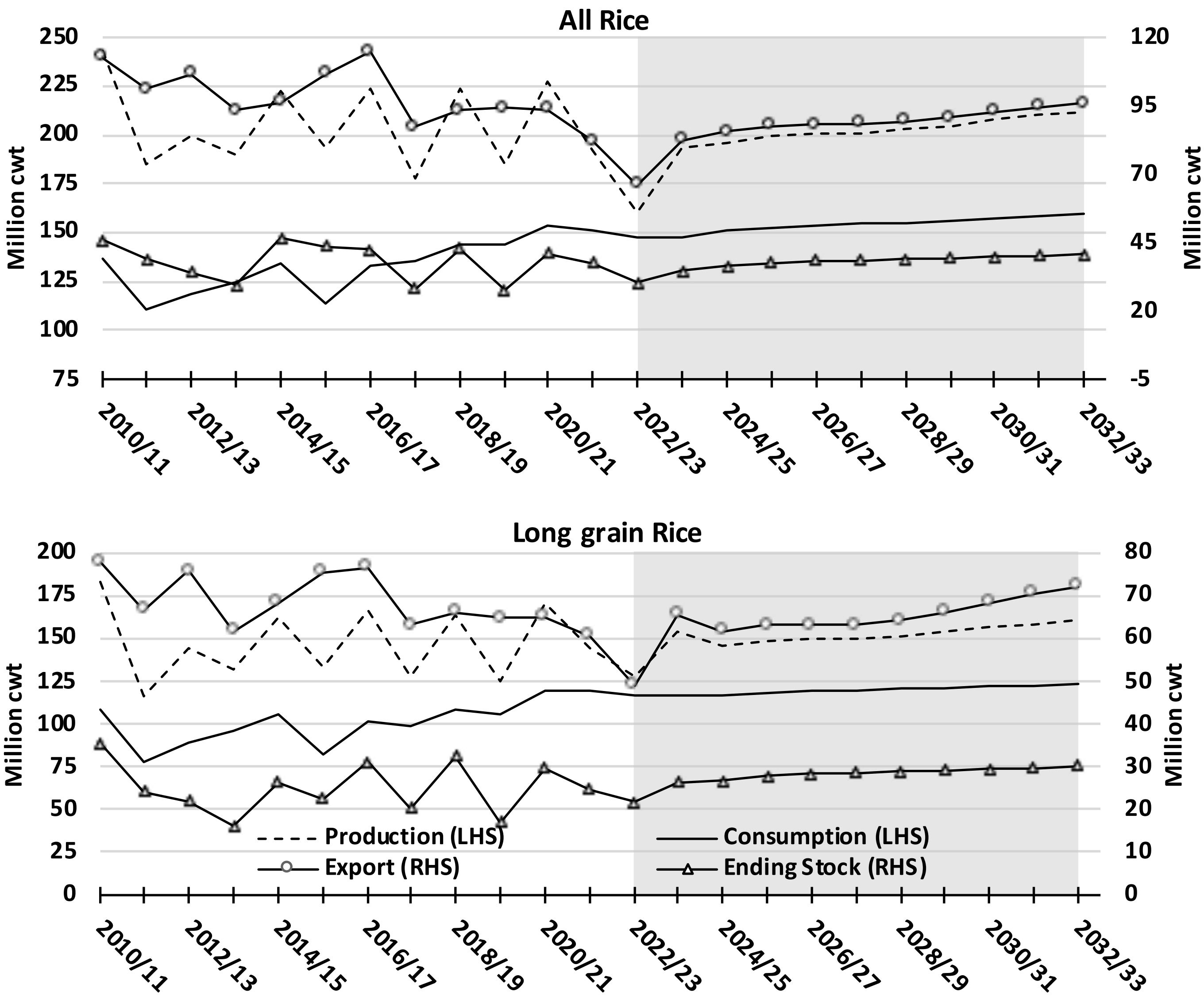
Source: USDA-ERS Rice Outlook, February 2023. AGRM projections January 2023.

Fig. 1. Annual Historical and Projected U.S. and Asian milled rice prices, US$ per metric ton, 2005–2032. The shaded area represents the projected period.



Source: USDA-ERS Rice Outlook, February 2023. AGRM projections January 2023.

Fig. 2. (left-hand side) Global rice production, consumption, (right-hand side) trade, and ending stocks, 2010–2032. The shaded area represents the projected period.



Source: USDA-ERS Rice Outlook, February 2023. AGRM projections January 2023.

Fig. 3. (left-hand side) United States rice production, consumption, (right-hand side) trade, and ending stocks, 2010–2032. The shaded area represents the projected period.

Number of Days Required to Plant the Arkansas Rice Crop

B. Badarch[1] and K.B. Watkins[2]

Abstract

The number of days available to plant rice in Arkansas during the planting season depends on spring weather conditions every year. This paper examines the number of acres planted per fieldwork day in Arkansas, the number of fieldwork days available for planting the entire rice crop in Arkansas, and the historical distribution of suitable fieldwork days per week for the optimal rice planting window in Arkansas using Arkansas Crop Progress and Condition Report data from 1981 to 2022. The average maximum acres planted per suitable fieldwork day for the Arkansas rice crop is 58,926 acres, and the average minimum number of suitable fieldwork days required to plant the entire Arkansas rice crop is 23 days. The average number of fieldwork days per week for Arkansas's optimum rice planting window (late March through the third week of May) is 4.5 days per week.

Introduction

Different spring weather conditions every year can make planting decisions difficult for rice producers. Weather dictates the number of days suitable for planting a crop and can lead to a shortened planting window or later planting dates. The Arkansas Rice Production Handbook indicates rice planted early generally has larger yields relative to rice planted later and recommends optimum planting dates ranging from 28 March to 20 May in eastern Arkansas (Hardke et al., 2021). Planting rice outside of these dates can significantly reduce rice yields. A late planting season can also lead to delayed harvest in the fall, where rain and dew could lead to reduced rice kernel quality and more considerable drying costs associated with the late harvest (Lu et al., 1995).

The objective of this paper is to estimate the minimum number of days required to plant the Arkansas rice crop based on historical data. We also want to compare the year-to-year variability associated with this number and the likelihood of having a sufficient number of suitable fieldwork days available for planting a rice crop on time. We base our analysis on weekly Crop Progress and Condition Report data and annual rice planted acreage data collected from the United States Department of Agriculture-National Agricultural Statistics Service (USDA-NASS) for 1981–2021. We feel this information will give rice producers better information for planting their future rice crops.

Procedures

This paper follows the procedures used by Irwin (2022) for calculating similar statistics for corn in the Corn Belt. We base our analysis on weekly USDA crop progress and condition report data for rice in Arkansas (USDA NASS, 2022a) along with Arkansas rice planted acreage data for the period 1981 and 2022 (USDA NASS, 2022b), supplemented by Arkansas days suitable for fieldwork data from Griffen (2009).

Based on Irwin (2022), our estimation procedures are as follows:

1. We estimate the maximum Arkansas rice acres planted per suitable fieldwork day for each year by i) multiplying each week's rice planting progress percentage for a given year by the total rice acres planted each year and ii) summing the two peak weekly acreages and dividing them by their respective sum of suitable fieldwork days,
2. We calculate the minimum number of suitable fieldwork days required to plant the rice crop each year by dividing the total planted rice acres by the estimated maximum rice acres planted per suitable fieldwork day, and
3. We calculate a frequency distribution to determine historical probabilities for the number of available suitable fieldwork days per week during the week 13 (the last week of March) through week 20 (the third week of May) planting window in Arkansas.

Results and Discussion

Maximum rice acres planted per suitable fieldwork day in Arkansas from 1981 to 2022 are presented in Fig. 1. The variation in maximum rice acres planted per suitable fieldwork day is noticeably different from one year to another, specifically between 2000 and 2014. This variation implies that weather conditions change the number of suitable fieldwork days available for planting rice every spring, which impacts planting progress each year. The trend for maximum planted rice acres in Arkansas has not noticeably changed over the study period, meaning there is no significant uptrend or downtrend trend. Overall, the average stays around 58,926 acres per suitable fieldwork day. Irwin (2022) also found no significant trend in Illinois's maximum corn acres planted per suitable fieldwork day from 1980–2021.

The minimum suitable days required to plant rice in Arkansas are presented for the period 1981 to 2022 in Fig. 2. Noticeably, the minimum number of days varies greatly by year due to variations in weather, especially between 2000 and 2020. The long-term average number of days needed to plant the rice crop stays at around 23

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days, with no significant trend up or down in the last 42 years. Thus, a minimum of 23 suitable fieldwork days are generally needed on average to plant the entire Arkansas rice crop based on historical data. Irwin (2022) also found no significant trend in the minimum number of fieldwork days required to plant the corn crop in Illinois using data from 1980–2021. He concluded that at least 14.3 days were needed on average to plant the corn crop in Illinois. Griffin and Kelley (2011) estimated 18.1 days were available for rice planting between 11th April and 9th May from 1975 to 2009. Our number is likely a bit larger because the Griffin and Kelly estimate is not based on planting all rice acres in a growing season as is our number but rather represents the number of suitable fieldwork days available on average for a specific planting window (11 April through 9 May). In addition, rice planting in Arkansas today can be much earlier than the early date used by Griffin and Kelley in 2011 (11 April) due to improvements in grain drill seed placement and increased usage of fungicide and insecticide seed treatment that have occurred over time.

The number of minimum days available for planting the rice crop varies significantly from year to year due to weather conditions, as shown in Fig. 2. The years 1985, 2003, 2007, 2011, 2013, and 2019 all have minimum suitable fieldwork days for planting rice in excess (plus one standard deviation or more) of 23 days. In 1985 and 2007, rice planting was delayed due to unusually cooler temperatures in the early spring. In years like 2003, 2011, 2013, and 2019, we had excessive rainfall in spring months at most locations in eastern Arkansas. Alternatively, years experiencing warm, dry weather in the spring (1982, 1992, 1993, 1994, 2002, 2005, and 2017) all had minimum suitable field days for planting rice below 23 days (minus one standard deviation or more). Thus, it makes sense why some years require more suitable fieldwork days to plant the rice crop than other years.

The historical distribution of suitable fieldwork days per week for rice in Arkansas from week 12 (late March) through week 20 (the third week of May) is presented for the period 1981–2022 in Fig. 3. Based on Fig. 3, there is a 23% chance for either 1, 2, or 3 suitable fieldwork days occurring per week and an almost 50% chance of either 5, 6, or 7 fieldwork days occurring per week. The average number of suitable fieldwork days per week is 4.5. Rice producers may use this information to estimate the number of days available to complete rice planting in years when rice planting has been delayed due to extreme weather. For instance, if most of a producer's rice acres have not been planted by the end of April due to weather conditions, the rice producer has roughly 3 weeks left to complete rice planting within the optimal planting window. Assuming the average of 4.5 suitable fieldwork days over the next 3 weeks, the rice producer would expect to have approximately 13.5 days available to plant the remaining rice acres. The producer then can decide to plant rice or to plant soybeans instead if soybeans would be more economically feasible.

Practical Applications

Planting windows shortened due to cool weather and excess rainfall in the spring can result in later planting of rice, potentially later rice harvests, and ultimately result in lower rice yields, reduced rice quality, and reduced profitability. In this paper, we review Arkansas's historical rice planting data for 1981–2022 and quantify critical statistics related to timely rice planting in Arkansas to provide helpful insights to rice producers. The conclusions of our analysis are as follows:

1. The maximum rice acres planted per suitable fieldwork day in Arkansas during the 42 years has not markedly changed. The overall average is 58,926 rice acres planted per suitable fieldwork day over the study period.
2. The minimum number of suitable fieldwork days necessary to plant the entire rice crop in Arkansas has historically averaged around 23 days but ranges from 17 to 34 days.
3. The weekly average number of suitable fieldwork days per week is 4.5 from the last week of March to the third week of May. The likelihood of having only 1, 2, or 3 suitable fieldwork days per week is 23%, while the likelihood of having either 5, 6, or 7 suitable fieldwork days per week is almost 50% during the given planting window.

A shortcoming of this study is that Arkansas crop progress and condition data are only reported for eastern Arkansas as a whole rather than for specific regions in eastern Arkansas. Crop progress and condition data by USDA, NASS crop reporting district rather than for eastern Arkansas as a whole could add greater accuracy to our analysis if such data were available.

Acknowledgments

This research was supported by the Arkansas Rice Check-Off funds administered by the Arkansas Rice Research and Promotion Board. Additional support was provided by the University of Arkansas System Division of Agriculture.

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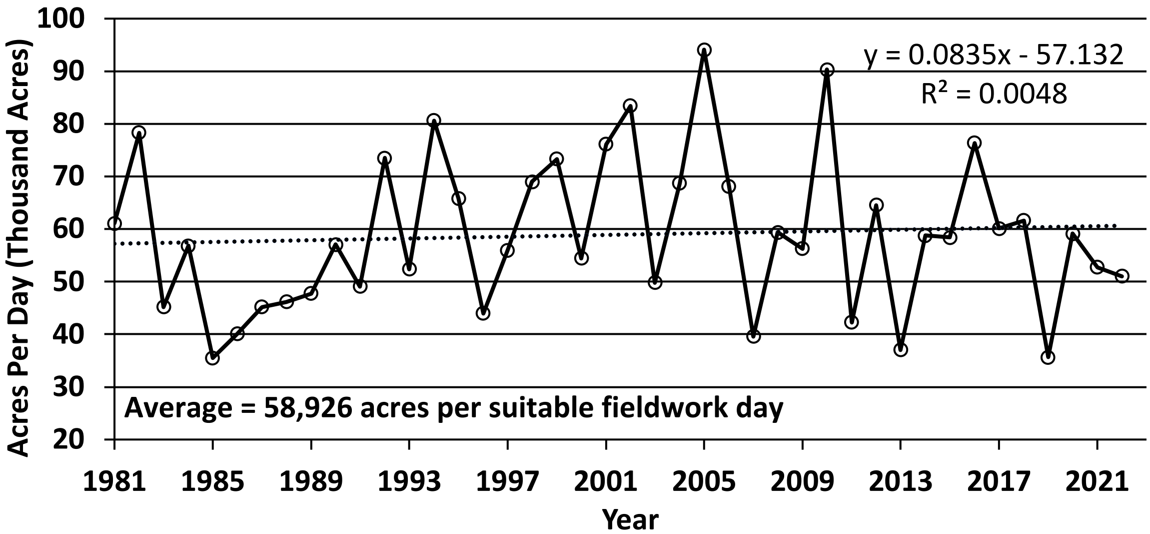

Fig. 1. Maximum rice acres planted per suitable fieldwork day in Arkansas, 1981–2022.

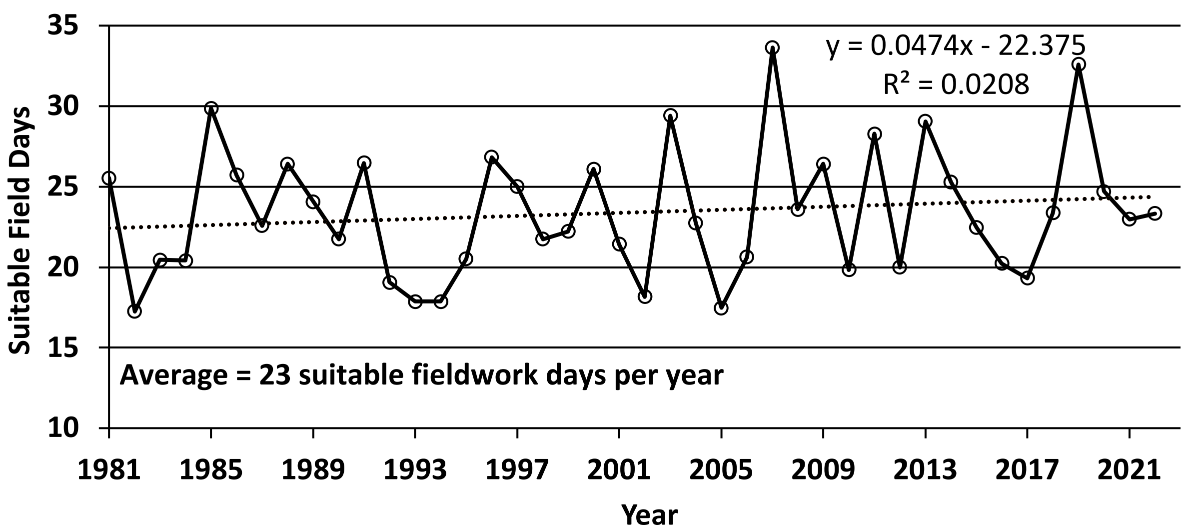

Fig. 2. Minimum suitable fieldwork days required to plant rice in Arkansas, 1981–2022.

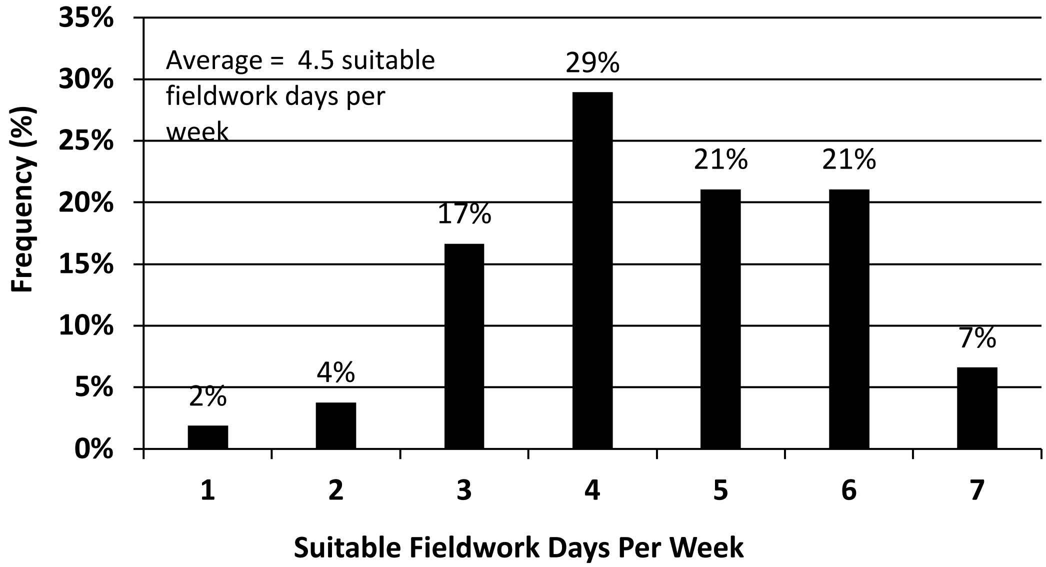

Fig. 3. Distribution of suitable fieldwork days per week for rice in Arkansas, last week of March through the third week of May 1981–2022.

Rice Enterprise Budgets and Production Economic Analysis

B.J. Watkins[1]

Abstract

Crop enterprise budgets are developed to be flexible for representing alternative production practices and cropping systems of Arkansas producers. Interactive budget programs apply methods that are consistent over all field crops. Production practices for base budgets represent University of Arkansas System Division of Agriculture's Cooperative Extension Service recommendations from Crop Specialists and from the Rice Research Verification Program. Unique budgets can be customized by users based on either Extension recommendations or information directly from on-farm decision-making and production practices. The budget program is utilized to conduct an economic analysis of field data in the Rice Research Verification Program. The crop enterprise budgets are designed to evaluate the solvency of various field activities associated with crop production. Costs and returns analysis with budgets allow for production economics analysis to investigate factors impacting farm profitability.

Introduction

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

Procedures

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

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

Ownership costs of machinery are determined by the capital recovery method, which determines the amount of money that should be set aside each year to replace the value of equipment used in production (Kay and Edwards, 1999). This measure differs from typical depreciation methods, as well as actual cash expenses for machinery. Amortization factors applied for capital recovery estimation coincide with prevailing long-term interest rates (Edwards, 2005). Interest rates in this report are from Arkansas lenders, as reported from September to October 2022. Representative prices for machinery and equipment are based on contacts with Arkansas dealers, industry list prices, and reference sources (Deere & Company 2022; MSU 2022). Revenue in crop enterprise budgets is the product of expected yields from following Extension practices under optimal growing conditions and commodity prices received data.

Results and Discussion

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

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ment of Crop, Soil, and Environmental Sciences. Actual production practices vary greatly among individual farms due to management preferences and between production years due to climactic conditions. 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 a basis for individual farmers developing budgets for their production practices, soil types, and other unique circumstances.

Table 1 provides a summary of revenue and expenses of the 2022 rice enterprise budgets. Costs are presented on a per-acre basis with an assumed yield of 170 bushels for conventional varieties and 190 bushels for hybrid. The price received for 2022 was set at $6.80/bu. Program flexibility allows users to change total acres, as well as numerous variables, to represent unique farm situations. Expected returns to total specified expenses range from $78.71 per acre (Provisia) to $186.09 per acre (Hybrid). The crop enterprise program includes budgets for Clearfield, Conventional, FullPage Hybrid, Hybrid, and Provisia seed technologies.

Practical Applications

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

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

Acknowledgments

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Table 1. Summary of revenue and expenses (dollars/acre), rice.

Receipts	Clearfield	Conventional	Full Page Hybrid	Hybrid	Provisia
Yield (bu.)	170	170	190	190	170
Price ($/yield unit)	6.80	6.80	6.80	6.80	6.80
Grower Share, %	100%	100%	100%	100%	100%
Crop Revenue	**1,156.00**	**1,156.00**	**1,292.00**	**1,292.00**	**1,156.00**
Operating Expenses					
Input Costs	732.69	708.37	797.05	765.10	748.91
Other Operating Expenses	109.78	109.24	111.21	110.50	110.14
Total Operating Expenses	842.47	708.37	908.27	875.61	859.05
Post-harvest Expenses	102.60	102.60	114.67	114.67	102.60
Net Operating Expenses	**895.94**	**920.20**	**1,022.93**	**990.27**	**961.65**
Cash Land Rent	0.00	0.00	0.00	0.00	0.00
Returns to Operating Expenses	**210.93**	**235.80**	**269.07**	**301.73**	**194.35**
Fixed Costs	115.64	115.64	115.64	115.64	115.64
Total Specified Expenses[a]	**1,060.71**	**1,035.85**	**1,138.57**	**1,105.91**	**1,077.29**
Returns to Specified Expenses[b]	**95.29**	**120.15**	**153.43**	**186.09**	**78.71**

[a] Does not include land costs, management, or other expenses and fees not associated with production.
[b] Share rent and cash land rent are deducted from crop revenue.

The Impacts of Weather on Arkansas Rice Monetary Returns in Northeast, East-Central, and Southeast Arkansas

K.B. Watkins[1] *and B. Badarch*[2]

Abstract

Weather can greatly impact rice grain yields. Large amounts of spring precipitation and cooler-than-average spring temperatures can push rice planting to later dates, resulting in significantly reduced rice grain yields and lower monetary returns. High temperatures in the summer months can also reduce rice grain yields. This study uses fixed effects regression models to determine the impacts of precipitation and temperature on rice monetary returns for 3 different rice subregions in Eastern Arkansas (Northeast, East-Central, and Southeast). Results indicate that weather impacts rice monetary returns differently across the three subregions in Eastern Arkansas when moving south to north. April precipitation has negative and statistically significant impacts on rice monetary returns in East-Central and Northeast Arkansas, but the impact of April precipitation on rice monetary returns in Southeast Arkansas is not statistically significant. High average temperatures in July and high average minimum temperatures in August have negative and statistically significant impacts on rice monetary returns in all 3 subregions, but the magnitudes of the negative impact vary by subregion.

Introduction

Although rice is an irrigated crop, weather can greatly impact rice grain yields. Excessive spring rainfall and cooler-than-average spring temperatures can push rice planting to later dates, resulting in significantly reduced rice grain yields and lower monetary returns (Watkins et al., 2022). There is also much evidence in the literature that high temperatures and high nighttime temperatures in the summer negatively affect rice grain yields. Peng et al. (2004) indicate that rice yields decline with higher nighttime temperatures resulting from global warming and report that rice grain yields decline 10% for every 1.8 °F (1 °C) increase in growing season minimum temperature. Lyman (2012) reports that a 1.8 °F (1 °C) increase in average growing season temperature reduces total edible rice yield in Arkansas by 9% to 9.9%. The Arkansas Rice Production Handbook reports that high- temperature stress causes increased sterility during flowering, and that high nighttime temperatures during grain filling increases plant respiration and causes the plant to consume more carbohydrates, which in turn reduces the efficiency of photosynthesis during the day, resulting in less filled spikelets, and leads to reduced grain yields and lower milling quality (Moldenhuer et al., 2021). Thus, the objective of this study is to determine the impacts of precipitation and temperature on rice monetary returns (defined as the product of rice grain yields and rice prices) in key subregions of Eastern Arkansas.

Procedures

The study area for this analysis is Eastern Arkansas, specifically counties contained in Arkansas Statistical Reporting Districts 3 (Northeast Arkansas), 6 (East-Central Arkansas), and 9 (Southeast Arkansas) that are maintained by the United States Department of Agriculture-National Agricultural Statistics Service (USDA-NASS). County rice yields, county planted acres, county weather data, and Arkansas market year average rice prices were collected for the period 1980–2021. Twenty-two Eastern Arkansas counties were included in the study. Four counties were excluded (Independence and White Counties in Northeast Arkansas; Crittenden and Lee Counties in East-Central Arkansas) due to missing yield observations.

County rice yields, county planted acres, and Arkansas market year average rice prices were collected from the USDA National Agricultural Statistics Service (USDA-NASS, 2023a). Trends were removed from all county rice yields to eliminate the effects of technological change in yields over time. Arkansas rice prices were converted to 2021 dollars using the Producer Price Index (U.S. Bureau of Labor Statistics, 2023). Rice monetary returns per year by county were then calculated as the Arkansas rice price converted to 2021 dollars multiplied by the detrended county rice yield. Monthly total precipitation and average temperature data for the months of March through October were collected for each county and year in the study using the PRISM (Parameter-elevation Regressions on Independent Slopes Model) interactive tool (PRISM Climate Group, 2023). The PRISM tool allows the user to obtain spatial climate data for the conterminous United States.

Fixed effects models were employed to determine the impacts of weather variables on rice monetary returns. A fixed effects model (also known as a dummy variable model) pools time-series and cross-sectional data together using dummy variables and assumes cross-sectional units can be adequately captured by different intercept coefficients for each cross-sectional unit (Judge et al. 1988). In this study, counties in Eastern Arkansas represent the cross-sectional units and rice monetary returns, county rice acres planted, and county monthly weather variables represent time-series observations. The fixed effects regression model is

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specified as follows:

$$RMR_{it} = \sum_{j=1}^{N} \beta_{1j} D_{jt} + \sum_{k=2}^{K} \beta_k X_{kit} + e_{it}$$

Where i = 1 to N counties; t = 1 to T years; j = 1 to N dummy variable coefficients; k = 2 to K slope coefficients; RMR_{it} = Rice Monetary Return for county i and year t ($/ac); X_{kit} = independent variables affecting rice monetary returns; D_{jt} = county dummy variables taking on the value of 1 when $j = i$ and 0 when $j \neq i$; β_{1j} = intercept coefficients for j = 1 to N counties; β_k = slope coefficients for k = 2 to K independent variables; and e_{it} = the error term for county i and year t.

Four fixed effects models were estimated, one 1 for Eastern Arkansas and three 3 for each subregion in Eastern Arkansas (Northeast Arkansas, East-Central Arkansas, and Southeast Arkansas). The explanatory variables used in each model included county rice planted acres (1000 ac), county total precipitation for the months of March through October (in.), county average temperatures for the months of March through July (°F), and county average minimum temperatures for the months of August through October (°F). County average monthly minimum temperatures represent a measure of nighttime temperatures as observed in other studies in the literature.

Results and Discussion

Estimated fixed effects model slope coefficients of weather impacts on rice monetary returns are presented for Eastern Arkansas and for the three subregions of Eastern Arkansas in Table 1. For the sake of brevity, county dummy variable coefficients are excluded from Table 1. The estimated coefficients for the Eastern Arkansas model vary in magnitude and often in statistical significance relative to the estimated coefficients for the three subregional models. In addition, the explanatory power of the Eastern Arkansas model, as measured by the adjusted R^2, is smaller than that for the three subregion models. These results imply weather impacts rice monetary returns differently when moving from south to north and that weather impacts estimated by the Eastern Arkansas model may either underestimate or overestimate weather impacts for each subregion. The remainder of the discussion will therefore focus on results by subregion.

It is hypothesized that the number of planted rice acres within a county will have a negative impact on rice monetary returns as more planted acres would indicate potentially more marginal land placed into production. Coefficients for planted rice acres were negative and statistically significant for all three subregions, although the magnitude of the planted rice acres coefficient for Northeast Arkansas (-$0.59 per acre per +1000 planted acres) was one-half that for East-Central Arkansas and Southeast Arkansas (-$1.19 and -1.20 per +1000 planted acres, respectively, Table 1), implying Northeast Arkansas has less marginal rice land relative to the other two subregions.

Precipitation in the Spring months had a negative impact on rice monetary returns, although the negative impact varied in both magnitude and statistical significance across the three subregions. March precipitation was negative and statistically significant in East-Central Arkansas, with one inch of precipitation in March resulting in a reduction in rice monetary returns of -$2.18 per acre (Table 1). March precipitation can delay field preparation prior to planting, resulting in planting delays and ultimately reduced grain yields. April precipitation impacts on rice monetary returns were negative and statistically significant in both East-Central Arkansas and Northeast Arkansas, with the largest negative impact occurring in Northeast Arkansas (-$4.42 per acre for each inch of precipitation, Table 1). March and April precipitation coefficients were not statistically significant in Southeast Arkansas. Rice field preparation and planting tend to be earlier in Southeast Arkansas, and rice monetary returns may be less susceptible to high levels of precipitation in Southeast Arkansas during the early Spring months.

Precipitation in May, June, and July negatively impacted rice monetary returns in all 3 subregions. However, the impacts were statistically significant during select months when moving south to north. May precipitation had a negative and statistically significant impact on rice monetary returns in Southeast Arkansas (-$4.38 per acre for each inch of precipitation), while July precipitation had a negative and statistically significant impact on rice monetary returns in East-Central Arkansas (-$2.83 per acre for each inch of precipitation) and Northeast Arkansas (-$5.35 per acre for each inch of precipitation). The negative impacts of precipitation on monetary returns in these months could possibly be due to flooding events but also could be due to extended periods of cloud cover, hindering sunlight and reducing photosynthesis during key rice growth and development stages. September precipitation had a positive impact on rice monetary returns in all three subregions, but the positive impact was statistically significant only in East-Central Arkansas (+$6.65 per acre for each inch of precipitation) and Northeast Arkansas (+$3.31 per acre for each inch of precipitation). October precipitation had a negative impact on rice monetary returns, with the largest negative impact occurring in Southeast Arkansas (-$3.40 per acre for each inch of precipitation).

Temperature strongly impacts rice monetary returns both positively and negatively within each subregion depending on the month. April and May average temperatures have a positive and statistically significant impact on rice monetary returns, as would be expected, with the greatest impact in April occurring in Southeast Arkansas (+$7.66 per acre for each 1 °F increase) and the greatest impact in May occurring in Northeast Arkansas (+$6.04 per acre for each 1 °F increase). June average temperatures negatively impact rice monetary returns in all 3 subregions, but the negative impact of June average temperatures is only statistically significant in Southeast Arkansas (-$4.46 per 1 °F increase). The largest negative impacts of average temperature on rice monetary returns occur in the month of July for all 3 subregions (-$9.76, -$12.85, and -$14.15 per acre for a 1 °F increase in East-Central Arkansas, Southeast Arkansas, and Northeast Arkansas, respectively), implying rice monetary returns are very susceptible to extremely hot weather in July.

Average minimum temperatures represent a measure of nighttime temperatures in this study, and increasing average minimum temperatures in August are hypothesized to have a negative impact on rice monetary returns. August average minimum temperatures indeed have a negative and statistically significant impact on rice monetary returns in all 3 subregions, with the largest negative impact occurring in Southeast Arkansas (-$7.16 per acre for each 1 °F increase), followed by Northeast Arkansas (-$5.53 per acre for each 1 °F increase) and East-Central Arkansas (-$4.58 per acre for each 1 °F increase). The negative impact of August average minimum temperatures is smaller in magnitude than the negative impact of July average temperatures in all 3 subregions, implying hot weather in July has a greater negative impact on rice monetary returns than high nighttime temperatures in August in all three subregions. September average minimum temperatures positively impact rice monetary returns in all 3 subregions, but the positive impact is statistically significant only in East-Central Arkansas (+$2.04 per acre for each 1 °F increase) and Northeast Arkansas (+$3.31 per acre for each 1 °F increase). Similarly, October average minimum temperatures positively impact rice monetary returns in all three subregions, but the positive impact is statistically significant only in East-Central Arkansas (+$2.19 per acre for each 1 °F increase) and Southeast Arkansas (+$4.52 per acre for each 1 °F increase).

Practical Applications

Perhaps the most significant finding of this study is that weather impacts rice monetary returns differently across the entire Eastern Arkansas region. Spring precipitation in March and April has less of an impact on rice monetary returns in Southeast Arkansas relative to East-Central Arkansas and Northeast Arkansas. Temperature impacts by month also differ in statistical significance and magnitude across the three subregions. These results imply that rice management recommendations, particularly with regard to timing of field operations, need to be better tailored for each rice-growing subregion in Eastern Arkansas due to weather variations. In addition, these results point to the need for more accurate measures of suitable fieldwork days per week, as reported by the USDA-NASS (2023b). Suitable fieldwork days per week are presently reported for the entire Eastern Arkansas growing region. The accuracy of this measure would be greatly improved if it were estimated for each subregion in Eastern Arkansas rather than for Eastern Arkansas as a whole.

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Table 1. Estimated fixed effects model coefficients of weather impacts on rice monetary returns, Eastern Arkansas and by region in Eastern Arkansas.

Independent Variables	Eastern Arkansas		Northeast		East-Central		Southeast	
Area Planted (1000 ac)	-0.8437	***[a]	-0.5955	***	-1.1928	***	-1.2065	***
	(0.1145) [b]		(0.2649)		(0.1897)		(0.3606)	
March Precipitation (in.)	-1.5871	***	-1.6543		-2.1846	**	-1.2572	
	(0.6114)		(1.9148)		(0.9846)		(1.0586)	
April Precipitation (in.)	-3.2815	***	-4.4266	***	-3.7482	***	-1.2772	
	(0.4989)		(1.5089)		(0.7542)		(0.9131)	
May Precipitation (in.)	-1.6479	***	-0.4923		-1.0152		-4.3860	***
	(0.5510)		(1.4767)		(0.8866)		(1.2385)	
June Precipitation (in.)	-0.5857		-1.8931		-0.2615		-1.5823	
	(0.6937)		(2.3468)		(1.0791)		(1.2759)	
July Precipitation (in.)	-2.1980	***	-5.3572	***	-2.8341	**	-0.3888	
	(0.7168)		(1.8253)		(1.2512)		(1.3713)	
Aug. Precipitation (in.)	-0.0669		2.1151	*	-2.0061		-1.5478	
	0.0000		(1.6761)		(1.3106)		(1.2226)	
Sept. Precipitation (in.)	3.3726	***	3.2462	***	6.6516	***	1.6821	
	(0.7175)		(1.8472)		(1.1790)		(1.5278)	
Oct. Precipitation (in.)	-2.4881	***	-2.7752	***	-1.7523	**	-3.4036	***
	(0.5246)		(1.4950)		(8.4210)		(1.0314)	
March Avg Temp (°F)	0.3553		-0.0111		-0.1084		0.6262	
	(0.3845)		(0.8640)		(0.5960)		(0.8799)	
April Avg Temp (°F)	5.9112	***	5.8012	***	5.9319	***	7.6631	***
	(0.4988)		(1.1804)		(0.7959)		(1.0489)	
May Avg Temp (°F)	4.9288	***	6.0488	***	4.1848	***	4.0168	***
	(0.6576)		(1.4256)		(1.0570)		(1.4628)	
June Avg Temp (°F)	-2.2618	***	-1.7353		-1.4444		-4.4675	**
	(0.8051)		(1.9128)		(1.2362)		(1.9818)	
July Avg Temp (°F)	-11.8013	***	-14.1564	***	-9.7697	***	-12.8594	***
	(0.8482)		(1.8334)		(1.3728)		(2.0979)	
Aug. Avg Min Temp (°F)	-4.9705	***	-5.5317	***	-4.5876	***	-7.1676	***
	(0.6847)		(1.6516)		(1.0716)		(1.5782)	
Sept. Avg Min Temp (°F)	2.5046	***	3.3168	***	2.0475	**	1.8578	
	(0.6109)		(1.4578)		(0.9550)		(1.2974)	
Oct. Avg Min Temp (°F)	2.5522	***	1.1761		2.1965	***	4.5222	***
	(0.5296)		(1.3173)		(0.8253)		(1.0881)	
Observations	907		328		333		246	
F-Statistic	19.51		13.86		13.09		9.88	
Adjusted R^2	0.4371		0.4856		0.4663		0.4436	
Root Mean Square Error	38.60		36.39		35.31		42.08	

[a] Asterisks ***, **, and * represent statistical significance at the 1%, 5%, and 10% levels, respectively.

[b] Numbers in parentheses are standard errors.

APPENDIX: RICE RESEARCH PROPOSALS

2022–2023 Rice Research Proposals

Principal Investigator (PI)	Co-PI	Proposal Name	Year of Research	Funding Amount (US$)
T. Butts	T Barber and J. Norsworthy	A Team Approach to Improved Weed Management in Rice	1 of 3	240,000
J. Hardke	T. Roberts, X. Sha, and C. De Guzman	Agronomic Production Practices for Rice	1 of 3	105,000
J. Hardke	T. Roberts, X. Sha, C. De Guzman	DD50 Thermal Unit Thresholds and Seeding Date Effects for New Cultivars	1 of 3	60,000
J. Hardke	T. Roberts, X. Sha, and C. De Guzman	Nitrogen Recommendations for New Rice Cultivars	1 of 3	57,000
N. Bateman	B. Thrash and N. Joshi	Rice Insect Management	1 of 3	130,000
T. Roberts	J. Hardke	Nitrogen Management Tools for Arkansas Rice Producers	1 of 3	115,000
T. Roberts	J. Hardke	Rice Fertilization-Developing Novel Methods to Assess Nutrient Availability to Arkansas Rice	1 of 3	58,000
B. Watkins	A. Durand-Morat and R. Mane	Economic Analysis of Arkansas Rice Farms	1 of 3	55,000
C De Guzman	X. Sha, J. Hardke, Y. Wamishe, and P. Counce	Breeding and Development of Improved Long-Grain and Aromatic Rice Varieties	1 of 3	305,000
X. Sha	C. De Guzman and J. Hardke	Quality Analysis for Rice Breeding and Genetics	1 of 3	113,836
X. Sha		Development of Superior Medium-Grain and Long-Grain Rice Varieties for Arkansas and the Mid-South	1 of 3	310,000
X. Sha		Breeding Hybrid Rice Varieties for Arkansas and Southern U.S.	1 of 3	185,000
A. Johnson	V. Boyett and X. Sha	Marker-Assisted Selection for Advanced Rice Breeding and Genetics	1 of 3	155,000

Continued

2022–2023 Rice Research Proposals, continued.

Principal Investigator (PI)	Co-PI	Proposal Name	Year of Research	Funding Amount (US$)
J. Hardke	T. Roberts, X. Sha, C. De Guzman, and Y. Wamishe	Arkansas Rice Variety Advancement Trials	1 of 3	90,000
J. Hardke	T. Roberts, X. Sha, C. De Guzman, N. Bateman, and Y. Wamishe	Arkansas Rice Performance Trials	1 of 3	100,000
C. De Guzman	X. Sha and Y. Wamishe	Rice Breeding and Pathology Technical Support	1 of 3	140,000
J. Hardke	B. Watkins	Rice Research Verification Program	1 of 3	107,714
G. Atungulu		Study of Cultivar Attributes and Their Measurements to Improve Rice Milling and Functional Characteristics	1 of 3	61,000
V. Ford	B. Watkins	Rice Enterprise Budgets and Production Economic Analysis	Ongoing	7,500
C. Henry	S. Sadaka, K. Brye, and R. Mane	Climate Smart 300 Bushel Row Rice on 12 inches of Automated Irrigation	1 of 3	85,000
A. Durand-Morat	B. Watkins and R. Mane	Analysis of Farm Policy Programs and Competitiveness of Arkansas and U.S. Rice	1 of 3	20,000
			Total:	**2,500,050**