B.R. Wells

Arkansas Rice Research Studies 2021

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

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Cover Photo: Terry Siebenmorgen was no stranger to fieldwork. Here, Siebenmorgen collects rice samples with former postdoctoral research associate Rusty Bautista, in a research project to determine the effects of nighttime air temperatures and moisture content at harvest on the milling and functional quality of rice.

Photo credit: University of Arkansas System Division of Agriculture.

Layout and editing by Gail Halleck

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

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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
Terry Siebenmorgen

Terry Siebenmorgen approached research like a detective—gathering clues, examining evidence, and building a case to solve mysteries that had plagued Arkansas' rice industry for years.

Siebenmorgen was a Distinguished Professor in the department of food science for the University of Arkansas System Division of Agriculture and the Dale Bumpers College of Agricultural, Food and Life Sciences at the University of Arkansas. He passed away on Nov. 22, 2020, following a battle with cancer. He was 63. He is survived by his wife, Patty, sons Justin and Ryan, and preceded in death by his son Matthew.

A native of Scranton in Logan County, Siebenmorgen earned his undergraduate degree from the University of Arkansas, his master's degree from Purdue University, and a doctorate from the University of Nebraska, all in agricultural engineering. He began his faculty career with the University of Arkansas System in 1984 as a food engineer, working in several areas of food processing. Starting in the late 1980s, he focused on rice processing in response to the substantial need for research from the food industry.

Man with a Mission

Siebenmorgen liked to say, "I always considered myself an engineer." But his friends and colleagues also knew him as a team-builder. In 1994, responding to post-harvest quality issues that baffled rice processing and food companies, Siebenmorgen assembled a crack team of Arkansas Agricultural Experiment Station scientists and founded the Arkansas Rice Processing Program. The Rice Processing Program marshaled the talents of world-class researchers, skilled research associates and technicians, and inquisitive graduate students to tackle the issues facing the rice industry. From the beginning, Siebenmorgen involved industry leaders to provide a two-way line of communication that fostered a flow of science-based solutions and constant feedback. This ongoing partnership reinforces and focuses the program's multidisciplinary research on rice processing operations.

Building on the program's industry relationships, Siebenmorgen established the annual Arkansas Rice Processing Program Industry Alliance Meeting that brings rice industry representatives from across the U.S. and around the world to the Arkansas Agricultural Experiment Station. "The meeting gives us a way to showcase the talents of our students, faculty, and staff while keeping industry in the loop on our research as it progresses," Siebenmorgen once said. "And it gives us direct feedback on the issues and research needs of the industry." Today, the Arkansas Rice Processing Program is world-renowned and has sponsors from across the United States, South America, Europe, and Japan. Industry representatives continue to flock to northwest Arkansas to rub shoulders with Rice Processing Program scientists, hear research reports and share their concerns with a program they know works diligently to find solutions to their problems.

Solving Mysteries

In the rice industry, two of Siebenmorgen's discoveries stand above the rest—uncovering the impact of high nighttime air temperatures on milling quality and understanding the glass phase transition. For years, rice millers were frustrated by inconsistent rice milling quality from one year to the next. A good year would mean that most of the milled rice that came out at the end of the process would have intact kernels that cooked properly and tasted good. A bad year saw mostly broken kernels and inconsistent cooking quality. Rice farmers were as confounded by the problem as rice processors. Poor milling quality meant they were paid less for their crops. The problem affected all rice varieties, regardless of who was growing them or where they were planted. And the pattern was completely random.

Years of research led Siebenmorgen to the conclusion that the problem was not caused by farmers' cultivation practices or by rice processing procedures. Taking a cue from Sherlock Holmes, Siebenmorgen and his team realized that if they eliminated all the impossible causes, then whatever remained must be the truth. If the inconsistent milling quality was not caused by variety choice, cultivation practices, or processing procedures, then there must be something happening in the plants themselves.

Siebenmorgen turned to crop physiologist Paul Counce at the Division of Agriculture's Rice Research and Extension Center near Stuttgart for help understanding what was happening. The research partners followed the clues and discovered that high night-time air temperatures impeded proper starch development in rice seed heads.

Siebenmorgen said the ultimate solution to the impacts of high nighttime air temperatures would likely be in the realm of rice breeding. The experiment station's rice breeding team added heat tolerance to the list of desired traits they work to achieve. In the meantime, planting earlier or using earlier maturing varieties could help growers avoid seed head development during the warmest months of the year.

In concurrent research, Siebenmorgen and his team were investigating how the physics of heat and the chemistry of starch formation met in the messy interface of rice biology during drying. The result was the discovery of the glass transition phase. Harvested rice kernels exist in a glassy state—the starch content of the seed is hard and glossy. Before milling, harvested rice is dried in a process that blows heated air through columns of falling seed. When heated, the starch content changes from glassy to rubbery—softer, duller in finish, and flexible. When it cools after drying, it returns to a glassy state.

What Siebenmorgen and his team discovered was that, because of non-uniform movement of moisture within the kernel, these changes can result in the formation of fissures in the starch. During milling, when rice kernels are tumbled like stones in a rock polisher to remove the husks and bran layer, they can crack apart at those fissures. The team was able to precisely map out how and when those glass transition phases occur. With that knowledge under his belt, Siebenmorgen was able to develop a new multi-stage drying procedure that reduced the likelihood that fissures would form. Siebenmorgen combined his expertise in rice processing, his skill in team-building, and his innate talent for leadership to provide solutions to two of the biggest problems facing Arkansas' rice industry.

Recognition

In 2019, Siebenmorgen was inducted into Class XXXII of the Arkansas Agriculture Hall of Fame. He was also inducted as a Fellow of the American Society of Agricultural and Biological Engineers in 2005 and the American Association of Cereal Chemists International in 2014. He earned many industry awards, including Riceland Foods' Friend of the Farmer in 2012 and the Distinguished Service Award from the Rice Technical Working Group in 2016 and 2018. He also received the American Society of Agricultural and Biological Engineers Distinguished Food Engineer Award in 2007. He was twice selected for the Texas Instruments Outstanding Research Award. He earned the Spitze Land Grant University Faculty Award for Excellence and John W. White Team Award, the highest award of its type given by the Division of Agriculture.

Legacy

"Terry was a true gentleman and a giant in his field. In addition to his great work for agriculture, he mentored a great number of students and post-docs who had the good fortune to work with him," said Mark Cochran, recently retired vice president for agriculture for the University of Arkansas System and head of the Division of Agriculture. "He dedicated himself to improving production and processing of a crop that is important not only in Arkansas but also is the most widely consumed grain in the world. He leaves a deep legacy for the industry in his work and on the students and colleagues on whose lives he made a great impact."

Jean-Francois Meullenet, senior associate vice president for agriculture-research and director of the Arkansas Agricultural Experiment Station, the research arm of the Division of Agriculture, was relatively new in his career at Arkansas when he met Siebenmorgen. "Terry was a great mentor to me throughout my faculty career, and he always made me feel welcome and wanted when it came to being a part of the Rice Processing Program," Meullenet said. "My participation in the Rice Processing Program allowed me to do a lot of fun research on rice quality and provided me great professional opportunities as an invited speaker at international venues in several countries, including South Korea and Uruguay. "When I became department head in 2008, Terry was a strong supporter of the work I did to advance the food science department. He always gave me sound advice and was always there for me," Meullenet said. "Many times, while meeting with Terry, an hour had passed before I would realize there was a long line of students and staff waiting patiently for him outside his door. I always walked out of his office with a calmer mind, renewed enthusiasm, and greater vision. Terry was that kind of guy. He loved to talk 'big picture.'"

"Dr. Siebenmorgen impacted so many people, and he is deeply missed," said Jeyam Subbiah, head of the food science department for the Division of Agriculture and Bumpers College. "His contributions towards research, teaching, leadership, and service to the rice industry will always remain. "He was one of the most optimistic and spiritual persons I have ever seen in my life," Subbiah said. "He treats his staff, students, and colleagues like members of his family. Besides being a kind-hearted man, he was also a loving husband, father, grandfather, friend, teacher, and co-worker."

Fred Miller
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

Most of the research results in this publication were made possible through funding provided by the rice farmers of Arkansas and administered by the Arkansas Rice Research and Promotion Board. We express sincere appreciation to the farmers and to the members of the Arkansas Rice Research and Promotion Board for their vital financial support of these programs.

The Arkansas Rice Research and Promotion Board

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Trends in Arkansas Rice Production, 2021

J.T. Hardke[1]

Abstract

Arkansas is the leading rice producer in the United States. The state represents 47.5% of total U.S. rice production and 47.8% of the total acres planted to rice in 2021. 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's Degree-Day 50 (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 lead 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 the 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 (https://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 the distribution of the most widely produced cultivars. RT 7321 FP was the most widely planted cultivar in 2021 at 24.0% of the acreage, followed by RT XP753 (22.4%), RT 7521 FP (19.2%), Diamond (6.3%), DG263L (4.8%), Jupiter (4.6%), CLL16 (3.5%), Titan (3.5%), RT 7301 (2.5%), and CLL15 (1.9%). Additional cultivars of importance in 2021, though not shown in the table, were PVL02, PVL03, ARoma17, CLM04, Jewel, CL111, and RT 7501.

Arkansas planted 1,211,000 acres of rice in 2021, which accounted for 47.8% of the total U.S. rice acres (Table 2). The state-average yield of 7,630 lb/ac (169.6 bu./ac) represented a 130 lb/ac increase compared to 2020. This resulted in a new state average yield record for Arkansas, greater than the previous record of 168 bu./ac set in 2013 and 2014. Regular early rainfall through April slowed planting progress compared to the 5-year average; however, progress achieved average pace by early May. Temperatures and conditions throughout the summer were clearly favorable for maximizing rice yield. Early harvest progress was slowed compared to the 5-year average, in line with the slower pace of planting. Heavy dews and stagnant temperatures limited the ability to take advantage of an early dry harvest window as grain moisture levels remained high. Unfortunately, periods of high nighttime temperatures, combined with the heavy dews, poor in-field grain drying conditions, and other factors, led to below-average milling yields for the season.

The final harvested acreage in 2021 totaled 1,194,000. The total rice produced in Arkansas in 2021 was 91.1 million hundredweight (cwt). This represents 47.5% of the 191.8 million cwt produced in the U.S. in 2021. Over the past three years, Arkansas has been responsible for 46.9% of all rice produced in the U.S. The largest rice-producing counties by acreage in Arkansas during 2021 included Lawrence, Poinsett, Jackson, Lonoke, Arkansas, and Cross, representing 42.4% of the state's total rice acreage (Table 1).

Planting in 2021 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 13% by 11 April compared to 23% averaged across the previous 5 years. Planting progress improved throughout April. As of 2 May, 63% of acres had been planted compared with an average of 66% by this date across the 5 previous seasons. By 6 June, 98% of acres had been planted compared to the 5-year average of 97%. As harvest began, temperatures and dewpoints remained stagnant. By 19 Sept., harvest progress had reached 48% compared to 58% for the 5-year average (Fig. 2). About 72% of the crop had been harvested by 3 Oct., compared with 82% harvest progress on the same date in previous years. It should be noted that many fields that appeared ready for harvest much earlier were delayed as grain finished maturing slowly and grain moistures remained high due to constant re-wetting and poor drying conditions. Harvest progress was complete (100%) by 14 November.

More rice is produced on silt loam soils (54.5%) than on any other soil texture (Table 3). Rice production on clay or clay loam soils (22.5% and 18.4%, 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.

Approximately 57% of the rice produced in Arkansas was planted using conventional tillage methods in 2021 (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 (35.6%) or no-till (8.0%) systems. True no-till rice production is not common but is practiced in a few select regions of the state.

Rice most commonly follows soybean in rotation, accounting for 66.4% of the rice acreage (Table 3). Approximately 22% of the acreage in 2021 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 3.3% 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 77.1% of the rice acreage in Arkansas, with the remaining 22.9% 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 2021, rice farmers utilize this practice on 32.8% of the rice acreage (Table 3). Most of the 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 3.5% 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 20.2% of acreage compared to 16.9% and 10.5% in 2020 and 2019, 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 2021, 37.5% of the acreage was burned, 44.2% was tilled, 31.6% was rolled, and 27.5% 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. In certain years, some practices can be inhibited by fall weather.

Contour levee fields accounted for 49.3% of rice acres in 2021 (Table 3). Precision-leveled, or straight levee, fields represented 38.7% and zero-graded fields 12.1%. 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 (81.4%) and grid soil sampling (41.0%) have increased slightly in recent years (Table 3). However, only 21.3% of rice acres are fertilized using variable-rate equipment. Urea stabilizers (products containing NBPT) are currently used on 92.2% 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 8.5% of acres, but additional tools are being developed to improve the confidence and adoption of this practice. In addition, programs such as Pipe Planner, PHAUCET, and MIRI Rice Irrigation were used on 33.6% of rice acres in 2021. A GreenSeeker handheld sensor was used to monitor in-season nitrogen condition on 3.6% of acres. The use of cover crops in rice rotations remains limited but was a practice used on 3.0% 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 31.7% of acres to improve harvest efficiency.

Pest management is vital to preserving both the yield and quality of rice. Foliar fungicide applications were made on 60.3% of rice acres in 2021 (Table 3). Conditions were not as favorable for the development of disease during the 2021 season. Approximately 46% 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 83.6% 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), FullPage™ (tolerant to imidazolinone herbicides), and Provisia® (tolerant to ACCase herbicides). Herbicide-tolerant cultivars (all technologies combined) accounted for 52.3% of the total rice acreage in 2021 (Fig. 3). Clearfield acres increased rapidly from 2001 to 2011 but have gradually declined since then. In 2018, Provisia became available on limited acres, and in 2021 was planted on 1.7% of acres. FullPage, similar to Clearfield, was launched in 2020 and in 2021 was planted to 43.2% 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. Evidence of these resistant populations may have served to reduce the number of Clearfield acres by emphasizing the negative effects of improper technology management. In addition, multiple years of this technology and crop rotation have likely cleaned up many red rice fields to the point where they can be safely returned to conventional rice production.

Practical Applications

State average yields over the past 20 years in Arkansas have increased from an average of 129 bu./ac in 1997–1999 to an average of 167.5 bu./ac in 2019–2021, an increase of 38 bu./acre. 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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Literature Cited

USDA-NASS. 2022a. United States Department of Agriculture National Agricultural Statistics Service. Accessed 17 Feb. 2022. https://downloads.usda.library.cornell.edu/usda-esmis/files/k3569432s/sn00c1252/g158cj98r/cropan22.pdf

USDA-NASS. 2022b. Quick Stats. United States Department of Agriculture National Agricultural Statistics Service. Accessed 17 Feb. 2022. https://quickstats.nass.usda.gov/

Table 1. 2021 Arkansas harvested rice acreage summary.

	Harvested Acreage[a]		Medium-grain			Long-grain								
County	2020	2021	Jupiter	Titan	Others[b]	CLL15	CLL16	DG263L	Diamond	RT 7301	RT 7321 FP	RT 7521 FP	RT XP753	Others[b]
Arkansas	88,601	70,089	652	179	502	762	2,403	1,962	3,035	137	21,693	14,805	17,405	6,553
Ashley	12,420	7,968	0	0	0	0	890	0	0	0	5,997	0	540	540
Chicot	27,929	18,314	0	0	0	0	0	0	0	0	5,409	5,091	2,706	5,107
Clay	75,751	69,757	4,744	105	313	3,079	3,347	4,239	4,527	0	16,288	14,316	10,035	8,766
Craighead	60,812	61,454	4,191	1,601	1,827	1,560	3,349	2,317	2,999	0	21,513	5,166	9,828	7,103
Crittenden	58,763	37,723	1,858	619	0	0	0	1,703	705	3,208	6,912	8,369	14,325	24
Cross	86,464	69,404	1,987	1,913	3,413	1,261	4,507	2,529	5,525	665	18,808	14,505	12,051	2,239
Desha	38,783	18,616	0	0	0	11	197	0	123	0	8,592	6,127	891	2,674
Drew	16,352	8,866	0	0	0	0	0	0	768	0	3,334	2,850	1,859	54
Greene	61,313	68,721	4,092	0	0	0	2,430	14,420	810	655	20,665	0	24,992	655
Independence	10,977	9,071	793	264	0	0	0	0	2,565	0	0	5,450	0	0
Jackson	98,580	93,444	5,861	10,304	17	2,115	1,733	443	12,408	663	14,589	12,899	19,692	12,719
Jefferson	75,827	48,426	1,369	456	0	0	1,307	8,473	808	0	14,927	18,465	32	2,587
Lawrence	81,514	102,192	6,243	11,661	0	5,587	2,458	6,507	10,131	4,362	22,209	4,955	27,693	386
Lee	24,294	11,527	84	0	0	0	0	394	914	1,109	1,977	1,318	5,731	0
Lincoln	30,177	17,129	0	0	0	0	0	0	358	0	10,348	5,552	872	0
Lonoke	92,448	75,811	2,969	0	692	3,066	744	458	0	6,640	15,951	18,608	23,873	2,809
Mississippi	67,237	56,771	1,009	0	0	0	0	2,129	2,398	56	9,256	13,806	27,556	560
Monroe	54,818	39,304	994	331	0	1,450	1,729	1,119	1,857	4,148	7,803	8,858	9,784	1,231
Phillips	37,301	15,613	0	0	0	0	0	0	1,849	4,520	0	0	9,244	0
Poinsett	116,444	95,617	14,436	2,114	4,803	2,133	8,651	2,757	11,453	0	11,048	19,159	10,783	8,280
Prairie	58,605	52,027	709	410	0	911	1,900	1,009	1,397	530	19,199	14,474	10,778	711
Pulaski	6,709	3,351	0	0	0	0	0	0	0	1,060	1,175	0	0	1,116
Randolph	33,990	37,409	35	11,159	0	0	600	2,348	2,113	1,174	5,811	2,994	7,090	4,086
St. Francis	38,979	30,244	503	205	0	22	636	1,413	4,139	777	5,288	8,652	8,089	518
White	6,726	4,756	135	0	0	0	0	0	1,768	0	1,486	624	743	0
Woodruff	52,163	48,912	1,734	438	0	593	1,935	3,093	458	383	15,352	20,528	4,153	244
Others[c]	21,486	19,896	0	0	0	124	3,161	0	1,585	0	1,268	1,500	7,045	5,214
Unaccounted[d]	5,538	1,586												1,586
2021 Total		1,194,000	54,400	41,761	11,567	22,674	41,978	57,313	74,693	30,088	286,902	229,071	267,792	75,763
2021 Percent		100.00	4.56	3.50	0.97	1.90	3.52	4.80	6.26	2.52	24.03	19.19	22.43	6.35
2020 Total	1,441,000		69,997	38,124	14,384	70,173	1,151	0	163,792	92,158	52,891	161,312	271,549	505,469
2020 Percent	100.00		4.86	2.65	1.00	4.87	0.08	0.00	11.37	6.40	3.67	11.19	18.84	35.08

[a] Harvested acreage. Source: USDA-NASS, 2022a.

[b] Other varieties: ARoma17, CL111, CL151, CL153, CLL17, CLM04, Jazzman-2, Jewel, LaKast, Lynx, ProGold1, ProGold2, PVL02, PVL03, Roy J, RT 7401, RT 7501, RT 7801, RT CLXL745, and RT Gemini 214 CL.

[c] Other counties: Clark, Conway, Faulkner, Franklin, Hot Springs, 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 2019 to 2021.[a]

State	Area Planted			Area Harvested			Yield			Production		
	2019	2020	2021	2019	2020	2021	2019	2020	2021	2019	2020	2021
	--------------(1,000 ac)--------------			--------------(1,000 ac)--------------			----------------(lb/ac)----------------			----------------(1,000 cwt[b])----------------		
AR	1,161	1,461	1,211	1,126	1,441	1,194	7,480	7,500	7,630	84,257	108,107	91,136
CA	503	517	407	501	514	405	8,460	8,720	9,050	42,362	44,810	36,653
LA	425	480	420	414	473	414	6,380	6,820	6,870	26,408	32,237	28,447
MS	117	166	105	113	165	100	7,350	7,420	7,540	8,302	12,241	7,540
MO	187	228	199	173	214	194	7,370	7,250	8,040	12,747	15,522	15,599
TX	157	184	190	150	179	181	7,350	8,150	6,860	11,028	14,597	12,421
US	2,550	3,036	2,532	2,477	2,986	2,488	7,473	7,619	7,709	185,104	227,514	191,796

[a] Source: USDA-NASS, 2022a.

[b] cwt = hundredweight.

Table 3. Acreage distribution of selected cultural practices for Arkansas rice production from 2019 to 2021.[a]

	2019		2020		2021	
Cultural Practice	**Acreage**	**% of Total**	**Acreage**	**% of Total**	**Acreage**	**% of Total**
Arkansas Rice Acreage	1,126,000	100.00	1,441,000	100.00	1,194,000	100.00
Soil Texture						
Clay	274,537	24.4	368,019	25.5	268,075	22.5
Clay Loam	233,341	20.7	300,045	20.8	220,061	18.4
Silt Loam	568,253	50.5	730,925	50.7	650,536	54.5
Sandy Loam	40,309	3.6	36,171	2.5	43,517	3.6
Sand	9,278	0.8	5,840	0.4	11,810	1.0
Tillage Practices						
Conventional	577,517	51.3	767,392	53.3	674,053	56.5
Stale Seedbed	435,702	38.7	543,562	37.7	424,978	35.6
No-Till	112,500	10.0	219,588	9.0	177,783	8.0
Crop Rotations						
Soybean	760,615	67.6	973,442	67.6	793,231	66.4
Rice	273,153	24.3	344,091	23.9	260,971	21.9
Cotton	1,727	0.2	2,755	0.2	1,591	0.1
Corn	51,815	4.6	55,566	3.9	68,557	5.7
Grain Sorghum	691	0.1	1,534	0.1	3,262	0.3
Wheat	4,693	0.4	2,344	0.2	3,093	0.3
Fallow	33,025	2.9	61,267	4.3	63,295	5.3
Other	0	0.0	0	0.0	0	0.0
Seeding Methods						
Drill Seeded	941,872	83.6	1,221,412	84.8	1,016,217	85.1
Broadcast Seeded	183,846	16.3	167,432	11.6	138,767	11.6
Water Seeded	58,156	5.2	52,156	3.6	39,016	3.3
Irrigation Water Sources						
Groundwater	871,110	77.4	1,114,374	77.3	921,097	77.1
Stream, Rivers, etc.	146,662	13.0	142,738	9.9	122,157	10.2
Reservoirs	107,946	9.6	183,887	12.8	150,747	12.6
Irrigation Methods						
Flood, Levees	633,240	56.2	712,463	49.4	519,261	43.5
Flood, Multiple Inlet	342,609	30.4	447,895	31.1	391,693	32.8
Intermittent (AWD)	31,196	2.8	35,873	2.5	41,668	3.5
Furrow	117,991	10.5	244,198	16.9	241,379	20.2
Sprinkler	682	0.1	571	0.0	0	0.0
Other	0	0.0	0	0.0	0	0.0
Stubble Management						
Burned	293,341	26.1	479,299	33.3	447,282	37.5
Tilled	392,884	34.9	530,180	36.8	528,258	44.2
Rolled	423,440	37.6	463,093	32.1	377,364	31.6
Winter Flooded	324,686	28.8	401,457	27.9	328,079	27.5
Land Management						
Contour levees	550,470	48.9	718,765	49.9	588,246	49.3
Precision-level	430,754	38.3	536,209	37.2	461,713	38.7
Zero-grade	144,495	12.8	192,149	13.3	144,040	12.1
Precision Agriculture						
Yield Monitors	867,793	77.1	1,141,788	79.2	971,576	81.4
Grid Sampling	426,851	37.9	520,921	36.1	489,135	41.0
Variable-rate Fertilizer	267,024	23.7	361,202	25.1	254,690	21.3
Use Pipe Planner, Phaucet	374,956	33.3	516,898	35.9	400,686	33.6
Use urea stabilizer (NBPT)	1,013,281	90.0	1,289,661	89.5	1,101,177	92.2
N-STaR	68,079	6.0	103,944	7.2	101,868	8.5
Use GreenSeeker handheld	42,352	3.8	40,183	2.8	42,480	3.6
Use Cover Crops	34,240	3.0	21,362	1.5	35,781	3.0
Use Sodium Chlorate	362,652	32.2	417,021	28.9	378,421	31.7
Pest Management						
Insecticide Seed Treatment	902,444	80.1	1,153,642	80.1	997,633	83.6
Fungicide (foliar app.)	585,688	52.0	868,717	60.3	719,455	60.3
Insecticide (foliar app.)	546,795	48.6	574,373	39.9	544,079	45.6

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

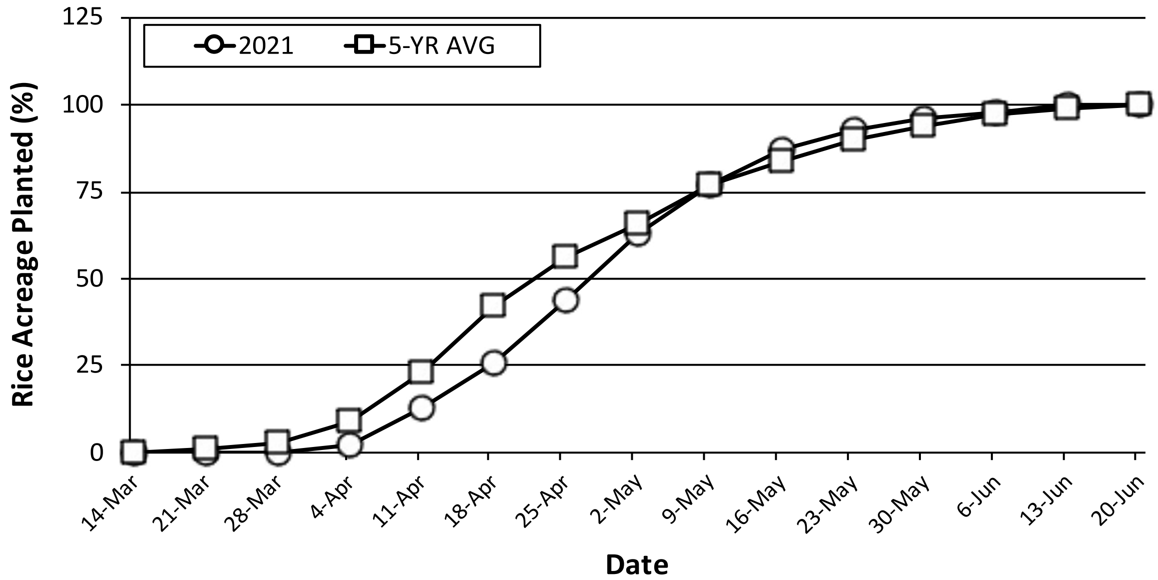

Fig. 1. Arkansas rice planting progress during 2021 compared to the five-year state average (USDA-NASS, 2022b).

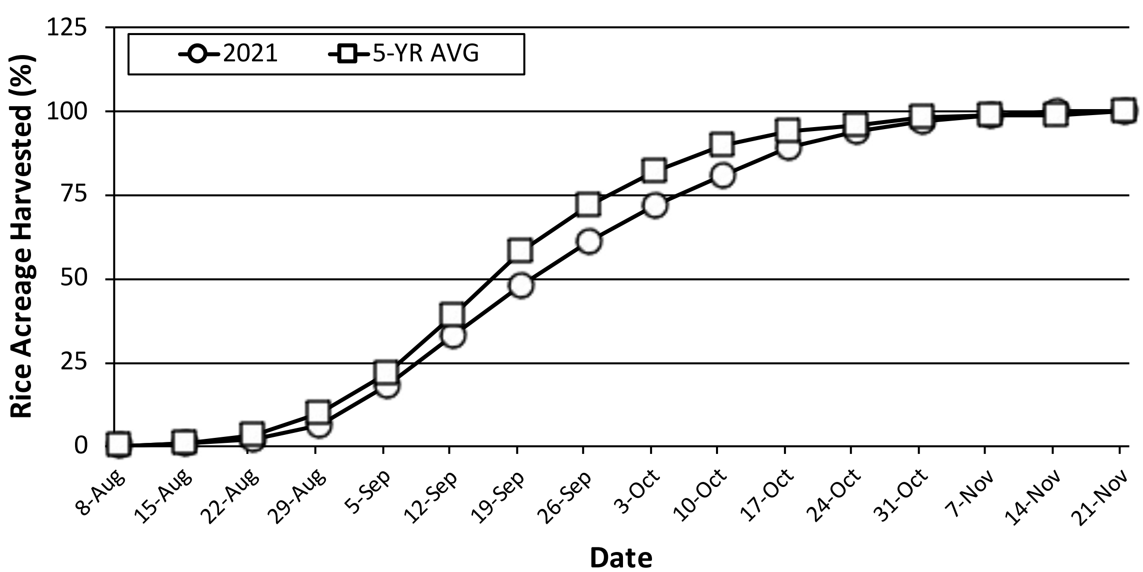

Fig. 2. Arkansas rice harvest progress during 2021 compared to the five-year state average (USDA-NASS, 2022b).

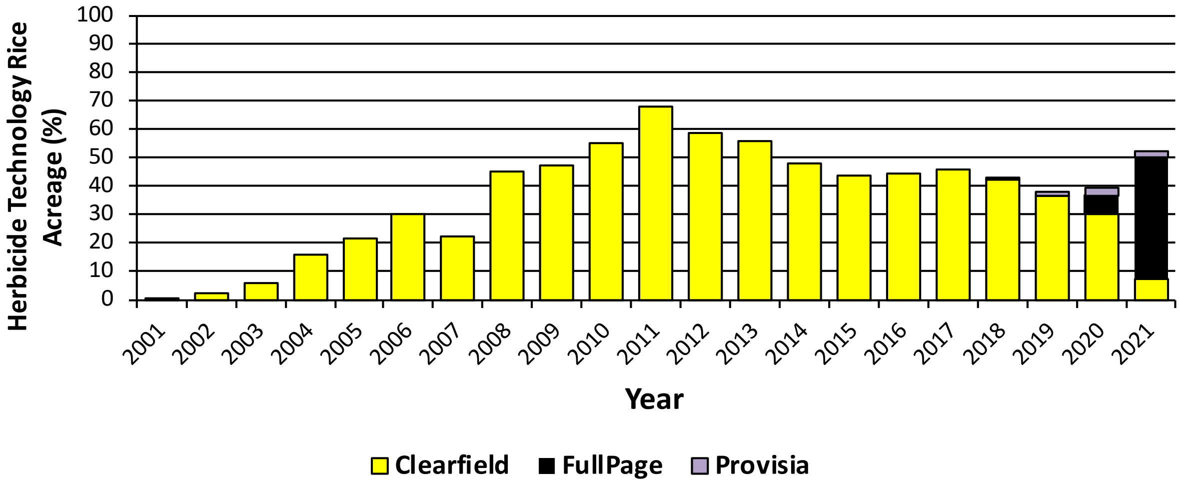

Fig. 3. Percentage of rice planted in Arkansas with herbicide technology including Clearfield, FullPage, and Provisia rice cultivars between 2001 and 2021.

2021 Rice Research Verification Program

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

Abstract

The 2021 Rice Research Verification Program (RRVP) was conducted on 8 commercial rice fields across Arkansas. Counties participating in the program included Arkansas, Chicot, Desha, Drew, Jefferson, Lonoke, Mississippi, and Monroe, for a total of 462 acres. Grain yield in the 2021 RRVP averaged 206 bu./ac, ranging from 172 to 243 bu./ac. The 2021 RRVP average yield was 36.4 bu./ac greater than the estimated Arkansas state average of 169.6 bu./ac. The highest yielding field was the furrow-irrigated rice field in Desha Co., with a grain yield of 243 bu./ac. The lowest yielding field was in Jefferson County and produced 172 bu./ac. Milling quality in the RRVP averaged 53/69 (% head rice/% total milled rice). The Mississippi Co. field had the greatest returns to operating costs of $725.13/ac, while the Lonoke Co. field had the lowest returns to operating costs of $468.12/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 the 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 2021 included: Arkansas, Chicot, Desha, Drew, Jefferson, Lonoke, Mississippi, and Monroe. The 8 rice fields totaled 462 acres enrolled in the program. Six different cultivars were seeded: RiceTec RT 7521 FP (3 fields); RT 7321 FP (2 fields); RT Gemini 214 CL (1 field); Dyna Gro DG263L (1 field), and Horizon Ag Provisia PVL02 (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 206 bu./ac with a range of 172 to 243 bu./ac (Table 1). All grain yields of RRVP fields are reported in dry bushels adjusted to 12% moisture. A bushel of rice is 45 lb. The RRVP average was 36.4 bu./ac more than the estimated state average yield of 169.6 bu./ac. Similar yield differences have been observed as the norm since the program began and can be attributed in part to intensive management practices and utilization of CES recommendations. The Desha County furrow-irrigated rice (row rice) field, seeded with RT 7321 FP, was the highest yielding RRVP field at 243 bu./ac. All 8 fields enrolled in the program met or exceeded the 169.6 bu./ac state

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average yield. Jefferson County encountered a late permanent flood (past optimum timing), resulting in the lowest yielding field with PVL02 producing 172 bu./ac.

Milling data was recorded on all the RRVP fields. The average milling yield for the 9 fields was 53/69 (% head rice/% total milled rice). The highest milling yield was 62/71 with PVL02 in Jefferson County (Table 1). The lowest milling yield was 47/67 with RT 7521 FP in Drew County. The milling yield of 55/70 is considered the standard used by the rice milling industry.

Planting and Emergence

Planting began with Drew County on 4 April and ended with Lonoke County on 19 May (Table 1). Six of the verification fields were planted in April and 2 in May. An average of 60 lb of seed/ac was planted for pure-line varieties and 24 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 16 plants/ft^2 for pure-line varieties and 8 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 two 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 5 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 handheld 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) fertilizer were applied based on soil test analysis recommendations (Table 2). Phosphorus was applied pre-plant to Chicot, Desha, Drew, Jefferson, Lonoke, Mississippi, and Monroe County fields. Potassium was applied to Arkansas, Lonoke, Mississippi, and Monroe County fields. Zinc was applied as a pre-plant fertilizer to the Lonoke County field, while zinc seed treatment was used with all hybrid and pure-line rice cultivars at a rate of 0.5 lb Zn/100 lb seed. The average per-acre cost of fertilizer across all fields was $101.22.

Weed Control

Clomazone (Command) herbicide was utilized as either a stand-alone, premix, or tank mix application in all 8 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 preemergence and early postemergence treatments. Overlapping residuals proved to be an effective strategy utilized in all 8 fields. All 8 fields utilized a combination of both grass and broadleaf residuals. Six fields (Chicot, Desha, Drew, Lonoke, Mississippi, and Monroe Counties) were seeded in imidazolinone (IMI) tolerant cultivars, either Clearfield or FullPage technologies (Table 1).

Disease Control

A foliar fungicide was applied in 4 of the 8 program fields (Arkansas, Drew, and Jefferson 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

Four fields (Chicot, Jefferson, Mississippi, and Monroe Counties) were treated with a foliar insecticide application for rice stink bug (Table 4). All 8 fields received an insecticide seed treatment.

Irrigation

Well water was used exclusively for irrigation in all 8 of the fields in the 2021 RRVP. Five fields (Arkansas, Chicot, Desha, 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 11.1 inches to a high of 28.8 inches.

Economic Analysis

This section provides information on production costs and returns for the 2021 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 2021 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 $517.67/ac for Jefferson County to $748.57 for Desha County, while operating costs per bushel ranged from $2.76/bu. for Mississippi County to $3.27/bu. for Chicot County. Total costs per acre (operating plus fixed) ranged from $611.38/ac for Jefferson County to $837.89/ac for Chicot County, and total costs per bushel ranged from $3.06/bu. for Mississippi County to $3.67/bu. for Chicot County. Returns above operating costs ranged from $468.12/ac for Lonoke County to $725.13/ac for Mississippi County, and returns above total costs ranged from $369.31/ac for Lonoke County to $654.52/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 2021 RRVP was 206 bu./ac but ranged from 172 bu./ac for Jefferson County to 243 bu./ac for Desha County. An Arkansas average long-grain cash price of $5.90/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 2021 loan values for whole kernels ($11.06/cwt; $4.98/bushel) and broken kernels ($6.76/cwt; $3.04/bushel). Estimated long-grain prices adjusted for milling yield varied from $5.65/bu. in Drew County to $6.06/bushel in Jefferson County (Table 7).

The average operating expense for the 8 RRVP fields was $629.81/ac (Table 7). Seed expenses accounted for the largest share of operating expenses on average (23.6%), followed by postharvest expenses (19.7%), fertilizers and nutrients (16.1%), and chemicals (13.5%). Although seed's share of operating expenses was 23.6% across the 8 fields, its average cost and share of operating expenses varied depending on whether a herbicide-tolerant cultivar was used ($71.50/ac; 13.8% of operating expenses), a proprietary non-herbicide tolerant pure-line cultivar was used ($97.50/ac; 16.34% of operating expenses), or a herbicide-tolerant hybrid was used ($169.65/ac; 25.9% of operating expenses).

The average return above operating expenses for the 8 fields was $565.64/ac and ranged from $468.12/ac for Lonoke County to $725.13/ac for Mississippi County. The average return above total specified expenses for the 8 fields was $481.94/ac and ranged from $369.31/ac for Lonoke County to $654.52/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 furrow-irrigated rice (FIR) field was located just west of Hagler (Bayou Meto) on a Hebert silt loam soil. The field consisted of 40 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 65 lb/ac planted on 6 April. Emergence was observed on 26 April with a stand count of 13.2 plants/ft^2. No tillage practices were used for spring field preparation. According to the soil test, fertilizer was applied at 0-0-60-0 lb/ac (N-P_2O_5-K_2O-Zn) in the spring. Glyphosate, Command, and League herbicides were applied at planting on 6 April. Command and Facet were applied as overlapping preemergence herbicides on 6 May. Facet L and Permit Plus were applied on 28 May for weed escapes. N-STaR (Nitrogen Soil Test for Rice) was taken on the field. Nitrogen in the form of urea plus an approved NBPT was applied at 100 lb/ac on 7 May, followed by 100 lb/ac on 14 June. Two more applications were made with 100 lb/ac on 21 June, followed by 100 lb/ac on 28 June. Using GreenSeeker, the N response levels remained adequate throughout the season. Intermittent flushing was utilized for irrigation. Sheath blight reached threshold level, and the field was treated with Quadris on 12 July. Rice stink bug numbers remained low and did not require treatment. The field was harvested on 3 September, yielding 188 bu./ac and a milling yield of 58/69. The average harvest moisture was 15.4%. Total irrigation was 18.7 acre-inches, and total rainfall was 22.2 inches.

Chicot County

The Chicot County furrow-irrigated rice (FIR) field was located southwest of Halley on Sharkey 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 26 lb/ac planted on 19 April. Emergence was observed on 28 April with a stand count of 6.3 plants/ft^2. No tillage practices were used for spring field preparation. According to the soil test, fertilizer was applied at 18-46-0-0 lb/ac (N-P_2O_5-K_2O-Zn) in the spring. Glyphosate, Command, and Sharpen herbicides were applied at planting on 19 April. Facet L and Command were applied as overlapping preemergence herbicides on 15 May. Preface herbicide was applied on 3 June. Postscript herbicide was applied on 24 June. N-STaR (Nitrogen Soil Test for Rice) was taken on the field. Nitrogen in the form of urea plus an approved NBPT was applied at 100 lb/ac on 18 May, followed by 100 lb/ac on 27 May. Two more applications were made with 100 lb/ac on 4 June, followed by 100 lb/ac on 11 June. Using Trimble GreenSeeker, the N response levels remained adequate throughout the season. Late boot N application 65 lb/ac was applied on 2 July. Intermittent flushing was utilized for irrigation. Propiconazole was applied on 3 July due to smut history. Rice stink bug numbers reached threshold levels, and Lambda cyhalothrin was applied on 23 July. The field was harvested on 8 August, yielding 228 bu./ac and a milling yield of 60/69. The average harvest moisture was 19.8%. Total irrigation was 21.3 ac-in., and rainfall totaled 20.8 inches.

Desha County

The Desha County furrow-irrigated rice (FIR) field was located just east of Arkansas City on Sharkey and Desha clay soils. The field consisted of 110 acres, and the previous crop grown was soybean. A pre-plant fertilizer blend of 18-46-0-0 lb/ac (N-P_2O_5-K_2O-Zn) was applied according to the soil sample analysis. The cultivar chosen was RT 7521 FP treated with the company's standard seed treatment. The field was drill-seeded at 27 lb/ac planted on 6 April. Emergence was observed on 16 April with a stand count of 7.2 plants/ft^2. No tillage practices were used for spring field preparation. Command, Facet L, and Sharpen herbicides were applied after planting on 7 April. Command and Prowl were applied as overlapping preemergence herbicides on 5 May. Preface herbicide was applied on 29 May. Nitrogen Soil Test for Rice (N-STaR) was taken on the field. Nitrogen in the form of urea plus an approved NBPT was applied at 100 lb/ac on 7 April, followed by 100 lb/ac on 7 June. Two more applications were made with 100 lb/ac on 13 June, followed by 100 lb/ac on 18 June. The late boot N application was applied on 12 July at 70 lb/ac. Using GreenSeeker, the N response levels remained adequate throughout the season. Intermittent flushing was utilized for irrigation. The field did not require a fungicide treatment, nor did it require a treatment for stink bugs. The field was harvested on 13 September, yielding 243 bu./ac and a milling yield of 58/69. The average harvest moisture was 17%. Total irrigation was 30 ac-in., and total rainfall was 28.8 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 35 acres, and the previous crop grown was soybean. The cultivar chosen was RT 7521 FP treated with the company's standard seed treatment. The field was drill-seeded at 25 lb/ac planted on 20 April. Emergence was observed on 29 April with a stand count of 9.9 plants/ft^2. No tillage practices were used for spring field preparation. According to the soil test, fertilizer was applied at 18-46-0-0 lb/ac (N-P_2O_5-K_2O-Zn) in the spring. Glyphosate, Command, and League herbicides were applied at planting on 20 April. Command and Facet L were applied as overlapping preemergence herbicides on 3 May. Preface herbicide was 28 May. N-STaR (Nitrogen Soil Test for Rice) was taken on the field. Nitrogen in the form of urea plus an approved NBPT was applied at 100 lb/ac on 4 May, followed by 165 lb/ac on 15 July, followed by 165 lb/ac on 18 June. Using GreenSeeker, the N response levels remained adequate throughout the season. Intermittent flushing was utilized for irrigation. Sheath blight disease exceeded threshold levels, and Quadris fungicide was applied on 15 July. Rice stink bug numbers remained low and did not require treatment. The field was harvested on 2 September, yielding 210 bu./ac and a milling yield of 47/67. The average harvest moisture was 15%. Total irrigation was 16.2 ac-in., and total rainfall was 18.6 inches.

Jefferson County

The 77-acre Jefferson County field was located just off the Arkansas River south of Altheimer on a Portland clay and Rilla silt loam soil. Conventional tillage practices were used for spring preparation. A pre-plant fertilizer blend of 0-50-0-0 lb/ac (N-P_2O_5-K_2O-Zn) was applied according to the soil sample analysis. The field was drill-seeded with PVL02 at 55 lb/ac. The seed was treated with CruiserMaxx Rice and zinc rice seed treatments. Rice emergence was observed on 24 May. Command and Roundup were used as preemergence and burndown herbicides on 16 May. Provisia was applied as a postemergence herbicide on 16 June. Using the N-STaR recommendation, N fertilizer in the form of urea plus NBPT was applied at 250 lb/ac on 18 June. The midseason N application was made on 12 July at 100 lb/ac. GreenSeeker was utilized during midseason growth stages to monitor the crop's N level. Armyworms reached threshold levels and were treated with Lambda-cyhalothrin plus Dimilin on 20 July. Due to a history of smuts, the field was treated with Propiconazole on 25 July. Stink bugs reached threshold levels and were treated with Endigo on 23 August. The field was harvested on 27 September. The yield was 172 bu./ac. The milling yield was 68/71, and average harvest moisture was 17%. Total irrigation use was 30 ac-in., and rainfall totaled 18.4 inches.

Lonoke County

The 81-acre contour field was located west of Parkers Corner on a Dewitt silt loam soil. Spring conventional tillage practices were utilized, and pre-plant fertilizer was applied at 0-40-60-0 lb/ac (N-P_2O_5-K_2O-Zn) according to the soil test. Glyphosate, Command, and Preface were applied as burndown and preemergence herbicides on 9 May. The cultivar RT 7521 FP treated with the company's standard seed treatment was drill-seeded at 22 lb/ac on 8 May. Stand emergence was observed on 19 May with 8.4 plants/ft^2. Preface and Facet were applied as postemergence herbicides on 26 May. Nitrogen fertilizer in the form of urea plus NBPT was applied on 18 May at 210 lb/ac according to the N-STaR recommendation. Multiple-inlet rice irrigation (MIRI) was utilized to achieve a more efficient permanent flood. GreenSeeker was utilized during midseason growth stages to monitor the crop's N level. The late boot N fertilizer application was made on 2 July at 70 lb/ac. The field was harvested on 24 September, yielding 180 bu./ac and a milling yield of 57/69. Total irrigation usage use was 30 ac-in., and total rainfall was 11.17 inches.

Mississippi County

The precision-graded Mississippi County field was located just west of Burdette on a Sharkey-Steel complex soil. Conventional tillage practices were used for field preparation in the spring. Based on soil test analysis, pre-plant fertilizer was applied at 0-50-60-0 lb/ac (N-P_2O_5-K_2O-Zn). Gramoxone was applied in the spring as a burndown herbicide. On 18 April, RT 7321 FP treated with the company's standard seed treatment was drill-seeded at 23 lb/ac. Command, Roundup, and League were applied on 18 April as preemergence and burndown herbicides. Stand emergence was observed on 29 April with 6.6 plants/ft^2. Preface and Facet herbicides were applied on 19 May. N fertilizer in the form of urea plus NBPT was applied at 260 lb/ac on 18 May, according to the N-STaR recommendation. The late boot urea application of 70 lb/ac was made on 16 July. Stink bugs reached threshold levels, and the field was sprayed with Mustang Maxx on 18 August. The field was harvested on 16 September, yielding 236 bu./ac with a milling yield of 63/73. The harvest moisture was 16%. Total irrigation use was 18.9 ac-in., and rainfall totaled 11.1 inches.

Monroe County

The 29-acre furrow irrigated (FIR) field was located in 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 fertilizer blend of 0-50-60-0 lb/ac (N-P_2O_5-K_2O-Zn) was applied on 4 April. The cultivar RT Gemini 214 CL treated with the company's standard seed treatment was drill-seeded at 20 lb/ac on 6 April. Command and Sharpen were applied at planting as preemergence herbicides. Emergence was observed on 27 April with 7.3 plants/ft^2. Command and Prowl were applied 14 May 14 as over-lapping preemergence herbicides. N-STaR (Nitrogen Soil Test for Rice) was taken on the field. N fertilizer in the form of urea was applied at 100 lb/ac on 15 May, followed by 100 lb/ac on 22 May. Another 100 lb/ac was applied on 5 June, followed by the late boot of 70 lb/ac on 16 July. GreenSeeker was utilized during midseason growth stages to monitor the crop's N level. Stink bugs reached threshold levels, and lambda-cyhalothrin was applied on 6 August. The field was harvested on 31 August, yielding 187 bu./ac. The milling yield was 64/69, and the average harvest moisture was 19%. Total irrigation for the season was 30 ac-in., and total rainfall was 11.75 inches.

Practical Applications

Data collected from the 2021 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 2021 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	DG263L	40	Soybean	65	13	6-May	26-May	3-Sept	188	58/69	15
Chicot	RT 7321 FP	49	Soybean	26	6	19-April	28-April	28-Aug	228	60/69	20
Desha	RT 7521 FP	110	Soybean	27	7	6-April	16-April	9-Sept	243	49/69	17
Drew	RT 7521 FP	35	Soybean	25	10	4-April	29-April	2-Sept	210	47/67	15
Jefferson	PVL02	81	Rice	55	19	16-May	24-May	27-Sept	172	62/71	17
Lonoke	RT 7521 FP	81	Soybean	22	8	8-May	19-May	24-Sept	180	47/69	14
Mississippi	RT 7321 FP	35	Soybean	23	7	18-April	29-April	16-Sept	236	50/71	16
Monroe	Gemini 214 CL	29	Soybean	20	7	6-April	27-April	31-Sept	187	47/68	19
Average		**57**	------	**33[b]**	**10[c]**	**11-May**	**24-May**	**14-Sep**	**206**	**53/69**	**17**

[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 2021 Rice Research Verification Program.

Field location by county	pH	Soil test P	Soil test K	Soil test Zn	Applied fertilizer: Mixed fertilizer[a] N-P-K-Zn[b]	Applied fertilizer: N-Star Urea (46%N) rates and timing[c, d]	Applied fertilizer: Total N rate[e]	Soil classification
		--(lb/ac)--			--(lb/ac)--		(lb N/ac)	
Arkansas	5.3	42	416	8.6	0-0-60-0	100-100-100-100-80	220	Hebert Silt Loam
Chicot	7.3	93	768	10.8	18-46-0	100-100-120-100-65	223	Sharkey Clay
Desha	7.4	43	636	6.6	0-50-0-0	100-100-100-70	216	Sharkey and Desha Clay
Drew	6.7	34	581	4.3	18-46-0-0	100-165-165	198	Portland Clay
Jefferson	7.0	62	352	6.6	0-50-0-0	250-100	161	Portland Clay and Rilla Silt Loam
Lonoke	6.1	30	209	3.3	0-40-60-5	210-70	129	Dewitt Silt Loam
Mississippi	7.1	64	423	9.5	0-50-60-0	260-70	152	Sharkey-Steele Complex
Monroe	7.1	35	198	6.8	0-50-60-0	260-70	170	Foley-Calhoun-Bonn Complex

[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. The mark (*) denotes an adjusted N-STaR rate and timing for furrow irrigated rice.
[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 2021 Rice Research Verification Program.

Field location by county	Pre-emergence herbicide Applications	Post-emergence herbicide applications
	----------(trade name and product rate/ac)[a]----------	
Arkansas	Glyphosate (32 oz) + Command (16 oz) + League (6.4 oz)	Command (16 oz) + Facet L (28 oz) FB Facet L (15 oz) + Permit Plus (0.75 oz)
Chicot	Select (12.8 oz) + Valor (2 oz) + Dicamba (8 oz) Command (16 oz) + Glyphosate (21 oz) + Sharpen (2 oz)	Command (16 oz) + Facet L (32 oz) FB Preface (6 oz) FB Postscript (5 oz)
Desha	Command (24 oz) + Facet L (32 oz) + Sharpen (3 oz)	Command (8 oz) + Prowl (2.1 pt)
Drew	Command (16 oz) + Glyphosate (32 oz) + League	Command (12 oz) + Facet L (32 oz)
Jefferson	Command (16 oz) + Glyphosate (32 oz)	Provisia (15.5 oz)
Lonoke	Command (16 oz) + Glyphosate (32 oz) + Preface (6 oz)	Preface (4 oz) + Facet L (32 oz)
Mississippi	Command (12.8 oz) + Glyphosate (32 oz) + League (6.4 oz)	Facet L (32 oz) + Preface (4 oz)
Monroe	Command (12.8 oz + (Sharpen (2 oz)	Command (12 oz) + Prowl (2.1 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 2021 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	DGST[a]	Quadris (10 oz)	------	------	------
Chicot	RTST[b]	------	------	------	Lambda-Cyhalothrin (2.5 oz)
Desha	RTST	------	------	------	------
Drew	RTST	------	------	------	------
Jefferson	CruiserMaxx Rice/Zinc	Propiconazole (6 oz)	------	------	------
Lonoke	RTST	------	------	------	------
Mississippi	RTST	Propiconazole (6 oz)	------	------	Mustang Maxx (2 oz)
Monroe	RTST	Propiconazole (6 oz)	------	------	Lambda-Cyhalothrin (2.5 oz)

[a] DGST = Dyna-Gro Seed Treatment.
[b] 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.

Table 5. Rainfall and irrigation information for fields enrolled in the 2021 Rice Research Verification Program.

Field location by county	Rainfall	Irrigation[a]	Rainfall + Irrigation
	(in.)	(ac-in.)	(in.)
Arkansas	22.2	18.7	40.9
Chicot	20.8	21.3	42.1
Desha	28.8	30*	58.8
Drew	18.6	16.2	34.8
Jefferson	18.4	30*	48.4
Lonoke	11.1	30*	41.1
Mississippi	11.1	18.9	30.0
Monroe	11.5	18.9	41.5

[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 2021 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	596.67	3.17	516.79	64.85	661.51	451.94	3.52
Chicot	744.68	3.27	614.50	93.21	837.89	521.29	3.67
Desha	748.57	3.08	648.31	78.69	827.26	569.62	3.40
Drew	672.62	3.20	513.66	70.60	743.22	443.06	3.54
Jefferson	517.67	3.01	524.80	93.70	611.38	431.09	3.55
Lonoke	559.64	3.11	468.12	98.81	658.45	369.31	3.66
Mississippi	650.44	2.76	725.13	70.60	721.04	654.52	3.06
Monroe	548.20	2.93	513.84	99.15	647.34	414.70	3.46
Average	**629.81**	**3.07**	**565.64**	**83.70**	**713.51**	**481.94**	**3.48**

Table 7. Summary of revenue and expenses per acre for fields enrolled in the 2021 Rice Research Verification Program.

Receipts	Arkansas	Chicot	Desha	Drew	Jefferson	Lonoke	Mississippi	Monroe	Average
Yield (bu.)	188	228	243	210	172	180	236	187	206
Price Received ($/bu.)	5.92	5.96	5.75	5.65	6.06	5.71	5.83	5.68	5.82
Total Crop Revenue	**1113.45**	**1359.18**	**1396.88**	**1186.28**	**1042.47**	**1027.76**	**1375.57**	**1062.04**	**1195.45**
Operating Expenses									
Seed	97.50	186.16	193.32	179.00	71.50	157.52	167.67	134.20	148.36
Fertilizers and Nutrients	111.71	116.40	130.93	107.86	90.38	81.20	81.62	89.70	101.22
Chemicals	110.77	120.99	93.27	102.64	52.17	68.61	82.45	50.48	85.17
Custom Applications	60.00	69.00	58.00	54.75	69.75	45.25	63.50	37.50	57.22
Diesel Fuel	5.54	8.81	6.35	6.34	12.44	10.76	9.54	9.53	8.66
Repairs and Maintenance	18.98	19.72	21.02	17.95	20.76	22.56	18.12	19.27	19.80
Irrigation Energy Costs	24.63	28.06	42.15	21.34	39.52	7.81	24.90	39.52	28.49
Labor, Field Activities	43.56	44.74	43.79	44.12	47.64	46.79	48.45	45.66	45.59
Other Inputs and Fees, Pre-harvest	10.52	13.21	13.10	11.88	9.71	10.52	11.76	9.48	11.27
Post-harvest Expenses	113.46	137.60	146.65	126.74	103.80	108.63	142.43	112.85	124.02
Total Operating Expenses	**596.67**	**744.68**	**748.57**	**672.62**	**517.67**	**559.64**	**650.44**	**548.20**	**629.81**
Returns to Operating Expenses	**516.79**	**614.50**	**648.31**	**513.66**	**524.80**	**468.12**	**725.13**	**513.84**	**565.64**
Capital Recovery and Fixed Costs	64.85	93.21	78.69	70.60	93.70	98.81	70.60	99.15	83.70
Total Specified Expenses[a]	**661.51**	**837.89**	**827.26**	**743.22**	**611.38**	**658.45**	**721.04**	**647.34**	**713.51**
Returns to Specified Expenses	**451.94**	**521.29**	**569.62**	**443.06**	**431.09**	**369.31**	**654.52**	**414.70**	**481.94**
Operating Expenses/Yield Unit	3.17	3.27	3.08	3.20	3.01	3.11	2.76	2.93	3.07
Total Expenses/Yield Unit	3.52	3.67	3.40	3.54	3.55	3.66	3.06	3.46	3.48

[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 2021 Rice Research Verification Program.

County	Rice type	Seed	Fertilizers and nutrients	Herbicides	Insecticides	Fungicides and other inputs	Diesel fuel	Irrigation energy costs
Arkansas	DG263L	97.50	111.71	94.47	---	16.30	5.54	24.63
Chicot	RT 7321 FP	186.16	116.40	113.88	2.73	4.38	8.81	28.06
Desha	RT 7521 FP	193.32	130.93	93.27	---	---	6.35	42.15
Drew	RT 7521 FP	179.00	107.86	86.34	---	16.30	6.34	21.34
Jefferson	PVL02	71.50	90.38	32.95	14.84	4.38	12.44	39.52
Lonoke	RT 7521 FP	157.52	81.20	68.61	---	---	10.76	7.81
Mississippi	RT 7321 FP	167.67	81.62	79.79	2.66	---	9.54	24.90
Monroe	Gemini 214 CL	134.20	89.70	47.76	2.73	---	9.53	39.52
Average	**---**	**148.36**	**101.22**	**77.13**	**5.74**	**10.34**	**8.66**	**28.49**

DNA Marker Analysis to Enhance Rice Variety Development

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Abstract

In 2021 molecular genetics staff at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC) performed genetic analysis for rice breeding projects involving DNA marker-assisted selection (MAS) for the traits of cooking quality, rice blast disease resistance, and the herbicide resistance technologies Clearfield and Provisia. The lab screened a total of 890 test samples with up to 8 markers. The rice molecular analysis projects included parental materials, backcross populations, and early and advanced generations of conventional breeding materials currently in development. In total, the lab generated 6,189 data points for 3 clients. The work was accomplished using 10 DNA template plates, 68 PCR plates, 10 runs on the ABI 3500xL to analyze simple sequence repeat (SSR) markers, and 29 PCR Allele Competitive Extension (PACE™) runs to analyze single nucleotide polymorphism (SNP) markers. Fifty-six percent of the data points were generated using the ABI 3500xL, while 44% were generated using an endpoint fluorescence platform (FLUOstar Omega SNP Reader) with PACE™ universal master mix. While developing new allele-specific SNP markers linked to the cooking quality gene *Waxy* and the rice blast disease resistance gene *Pi-ta* the molecular genetics lab also modified existing SNP markers linked to the traits of gelatinization temperature, aroma, and glabrous leaf and sheath.

Introduction

Over the last 21 years, much of the effort of the molecular genetics lab has been devoted to the genotypic characterization of parental lines and progeny in the development of new long-grain and medium-grain cultivars. Using DNA Marker-assisted Selection (MAS) can be a powerful tool for the rice breeder to evaluate and characterize germplasm resources, aid in selection for different agronomic traits, track gene introgression, predict hybrid performance, and monitor seed quality in the final stages of the seed production process (Xu, 2003). Most importantly, using DNA markers can confirm hybridity and seed purity without the influence of growth stage and environmental conditions.

The objective of this ongoing study is to apply specific DNA marker technology to assist with the development of elite cultivars adapted to Arkansas with higher yields, improved cooking quality, and rice blast disease resistance. The goals include (i) characterizing parental materials on a molecular level for important agronomic traits and purity, (ii) performing DNA MAS of progeny to confirm identity and track gene introgression, and (iii) ensuring seed quality and uniformity by eliminating off types.

Procedures

Some samples consisted of leaf tissue from individually tagged greenhouse plants that were collected in manila coin envelopes and kept in plastic bags on ice until placed in storage at the molecular genetics lab. Other samples were brought to the molecular genetics lab as seed, which were germinated at 84.2 °F (29 °C) in Petri dishes in an incubator (VWR Scientific, Radnor, Pa.). The leaf tissue was stored at -112 °F (-80 °C) until processing. Total genomic DNA was extracted from the leaf tissue using a rapid method with Sodium hydroxide/Tween 20 buffer, 10-min incubation at 203 °F (95 °C), and neutralization with 100 mM TRIS-HCl, 2 mM EDTA (Xin et al., 2003).

Each set of DNA samples was arrayed in a 96-well format, processed through a OneStep-96 PCR Inhibitor Removal system (Zymo Research Corporation, Irvine, Calif.), and used directly as the starting template for SSR and insertion-deletion (InDel) marker analysis. For PACE reactions, the DNA plate was diluted 1:5 in low-EDTA TE buffer to prepare the reaction template.

Polymerase Chain Reaction of SSR and InDel markers was conducted using primers pre-labeled with attached fluorophores of either HEX, FAM, or NED by adding 2 µl of starting DNA template in a final reaction volume of 25 µl and cycling in a Mastercycler X50s thermal cycler (Eppendorf North America, Inc., Westbury, N.Y.) for 35 cycles of a traditional 3-step PCR protocol. PCR plates were grouped according to allele sizes and dye colors and diluted together to save on processing and analysis costs. The PCR products were resolved using capillary electrophoresis on an ABI 3500xL Genetic Analyzer (Applied Biosystems, Foster City, Calif.). Data were analyzed using GeneMapper Software V5.0 (Applied Biosystems, Foster City, Calif.).

The PACE reactions were prepared by adding 5 µl of each DNA sample and 5 µl of the PACE 2X Master Mix (3CR Bioscience, Harlow, Essex, U.K.) containing 0.14 µl of Assay Mix (Integrated DNA Technologies, Coralville, Iowa) to the wells of a 96-well opaque qPCR plate (LGC Biosearch Technologies, Teddington, Middlesex, U.K.). The plate was then sealed with qPCR film (LGC Biosearch Technologies, Teddington, Middlesex, U.K.), and the PACE reactions were cycled in a Mastercycler

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X50s thermal cycler (Eppendorf North America, Inc., Westbury, N.Y.) using a 2-step 135 °F (57 °C) thermal cycling protocol. The plates were then allowed to cool to room temperature prior to reading on a BMG Labtech FLUOstar Omega SNP plate reader (LGC Biosearch Technologies, Teddington, Middlesex, U.K.). Detected fluorescence was analyzed using KlusterCaller software (LGC Biosearch Technologies, Teddington, Middlesex, U.K.).

Markers used to analyze the test samples included the *Pi-ta* marker Pi-indica and the *Ptr* gene marker Z12, the *Pi-k* rice blast resistance gene marker RM224, and the markers to assess cooking quality: RM190, *Waxy* Exon 1, *Waxy* Exon 6, and *Alk*. The markers Pi-indica, Z12, RM224, and RM190, were grouped together in the same ABI plate, while the remaining cooking quality markers were analyzed using the PACE system.

Results and Discussion

Long-Grain, Medium-Grain, Hybrid Rice Breeding Programs. As measured in data points generated, 89% of the marker analysis was marker-assisted selection conducted for these rice breeding programs. The analysis covered conventional long-grain, Clearfield, and Provisia line development. The samples were screened with markers linked to the traits of cooking quality, rice blast disease resistance, and the Clearfield trait.

High Nighttime Temperature Project. One project, which constituted 3% of the total marker analysis effort in 2021, involved screening samples with polymorphic markers linked to the traits of cooking quality, rice blast disease resistance, and plant height to confirm that they were the true progeny of a backcross and not selves.

Proprietary Client. A marker analysis project was conducted for variety confirmation purposes. The data points generated comprised 8% of the total effort for 2021.

Practical Applications

Marker-assisted selection enables rice breeders to make their selections rapidly and efficiently, saving time, field resources, and labor. Many traits would require the plant to grow to maturity to assess them phenotypically. A compilation of all the marker analyses conducted enables the rice breeder to make selections of plants with desirable agronomic traits. Using markers allowed selection to take place in an early generation so that most of the investment in development could be focused on promising lines and not wasted on materials destined to be discarded.

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Literature Cited

Xin, Z., J.P. Velten, M.J. Oliver, and J.J. Burke. 2003. High-Throughput DNA Extraction Method Suitable for PCR. BioTech. 34:4:820-825.

Xu, Y. (2003) Developing Marker-Assisted Selection Strategies for Breeding Hybrid Rice. In J. Janick (Ed.), Plant Breeding Reviews, Volume 23 (pp. 73-174). Hoboken, NJ: John Wiley & Sons, Inc.

Development of Long-Grain Conventional and Herbicide Tolerant Rice for Arkansas and the Mid-South

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Abstract

The long-grain rice breeding program in the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC) has a long history of successfully developing long- and medium-grain as well as specialty rice cultivars for the Arkansas rice producers and the mid-South. Selections and evaluations are strictly conducted based on the desirable characteristics that need to be improved. These important characteristics include high rough rice yield potential, high milling yields, disease resistance, abiotic tolerance, good plant stature, and superior grain quality (i.e., low chalk, processing, cooking, and eating qualities). In 2021, a total of 1,204 entries entered the yield trials of both initial and advance tests for a total of more than 4,000 yield plots, including plots for seed increases. This report presents the overall results of the 2021 breeding program that includes lines from both initial and advance tests as well as potential lines in the pipeline.

Introduction

The long-grain breeding program in Arkansas develops new varieties using different conventional and advanced breeding methodologies. We incorporate resistance/tolerance traits to combat major rice diseases and evaluate lines with excellent grain and milling yields. This is achieved through crossing, backcrossing, marker-aided selection (MAS), and other feasible techniques. We use the winter nursery in Puerto Rico as well as the greenhouse located at RREC near Stuttgart, Arkansas, to accelerate the breeding process. Furthermore, herbicide tolerance traits Clearfield and Provisia are also being incorporated into elite Arkansas rice lines or varieties. Each year, more than 1,200 entries are evaluated in advance and initial yield tests. We made 200–300 crosses and planted approximately 6,000 panicle rows and more than 40,000 F_2 plants. The program also cooperates with the extension agronomist to conduct a comprehensive rice variety testing program in all major rice-producing areas of the state. We also participate in the Uniform Regional Rice Nursery conducted in Arkansas, Louisiana, Mississippi, and Texas.

Procedures

Two Advanced Yield Trials (AYT) of the conventional long-grain were conducted in 2021. One was at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC) in Stuttgart and the other at the Pine Tree Research Station (PTRS) near Colt, Arkansas. The AYT at PTRS has 55 entries, while the AYT at RREC has 55, with an additional 22 entries from the high nighttime temperature project. In the Stuttgart Initial Trial (SIT), the large number of entries were grouped into three subtrials as SIT-A, SIT-B, and SIT-C. Subtrial SIT-A is for the most advanced lines (F_6-F_7) with 88 entries, SIT-B is for the F_5-F_6 generations with 121 entries, and SIT-C is for the early generation lines F_4-F_5 which consisted of 561 entries. Under the herbicide-tolerant long-grain program, we have three yield trials conducted: IMI Advance Yield Trial (IMI-AYT), IMI Stuttgart Initial Trial (IMI-SIT), and Provisia Stuttgart Initial Trial (Prov-SIT). There were 59, 194, and 136 entries for IMI-AYT, IMI-SIT, and Prov-SIT, respectively. All yield trials were replicated three times in a randomized complete block design. We used a six-row planter with a plot size of 12 ft × 3.75 ft for AYT and IMI-AYT and 8 ft × 3.75 ft in SIT-A, SIT-B, SIT-C, IMI-SIT, and Prov-SIT. With the exception of SIT-C and AYT located in the PTRS, one additional plot was planted for all initial tests and 2 more plots for all advanced tests dedicated to seed increase. The combined yield trials totaled more than 4,000 plots. The plots were harvested using the Wintersteiger Quantum plot combine, and grain yields were calculated as bushels per acre (bu./ac) at 12% moisture content. The milling yields as percent total and percent head rice were taken using Zaccaria PAZ-100 sample mill. Analysis of variance (ANOVA) from yield trials was performed using R, and multiple comparisons were analyzed using Fisher's least significant difference at $P \leq 0.05$.

Results and Discussion

Conventional

In the conventional long-grain advance yield trial (AYT) located at the RREC, 23 entries had a higher yield than the check variety Diamond. However, there were no significant differences

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detected when tested using multiple comparisons. Percentage total rice and head rice milling yields showed significant differences, wherein most entries have higher total and head rice yield compared to Diamond. Table 1 shows the top ten entries with the highest yields in the AYT tested at RREC. Similarly, no significant differences in yield were observed in AYT located at PTRS when tested by multiple comparisons. Table 2 shows the top ten entries with the highest yields in AYT at PTRS, including the check LaKast and Diamond. The Stuttgart Initial Trial SIT-A in Table 3 shows that the top four high-yielding lines do not differ in yield from Diamond. Nonetheless, the three top lines can be moved to the advanced yield trial due to better milling yields. In SIT-B, twenty entries yielded higher than the check Diamond, but only one is significantly higher based on the LSD test. Entry STG20L-072 yields an average of 264 bu./ac with milling yields of 47/69 of head/total rice compared to Diamond at 239 bu./ac and with 42/67 milling yield (Table 4). In SIT-C, 49 out of 561 entries have a higher yield than Diamond.

Clearfield

The IMI-AYT is composed of 59 entries, including 6 checks. Table 5 shows 20AR1093 (CLL18) with a grain yield of 268 bu./ac, having significantly out-yielded the check varieties CLL16, CL111, and CL172 with 243, 215, and 204 bu./ac, respectively. Entry 20AR1093 was recently released as CLL18. Eleven more entries have higher yields than the check CL111 and CL172 but do not differ statistically from CLL16 according to multiple comparisons. The variety CLL18 is two days earlier than CLL16 but 8 days later than CL111 and CL172. The milling yield of CLL18 is higher at 50/68 head rice/total rice compared to CLL16, CLL111, and CL172 at 39/62, 40/63, and 49/66, respectively.

In IMI-SIT, there are 7 entries with yields higher than the check CLL16 but were not significantly different using multiple comparisons (Table 6). The top three highest yielding entries are STG20IMI-376, STG20IMI-141, and STG20IMI-181, with a grain yield of 282, 279, and 275 bu./ac, respectively, compared to CLL16 with 268 bu./ac. Lodging was observed on the two highest yielding entries but not on the check varieties.

Provisia

Out of 136 entries in Prov-SIT, there are 13 entries that out-yielded the check variety PVL02 (Table 7). Four of these entries are significantly higher based on the LSD test at $P \leq 0.01$. These four entries are STG20PR-003, STG20PR-089, STG20PR-060, and STG20PR-054 with 180, 178, 172, and 165 bu./ac, respectively, compared to PVL02 with 146 bu./ac. No significant differences were observed for heading, height, and milling yield of all the entries in the trial.

Crosses, F_2 Populations, and Panicle Rows

In 2021, we made 274 successful crosses, including 40 Provisia crosses, 129 conventional crosses, 80 Clearfield crosses, and 25 testcrosses using CMS male-sterile lines. In the field, we grew 14 conventional F_2 populations and 17 Clearfield F_2 populations with approximately 1,000 plants/population, totaling 30,000 plants. We selected 4,000 individual plants and harvested individual panicles from those populations. We employed a rapid generation advancement in the greenhouse by growing 12,000 F_2 conventional and provisia plants in 96 cell trays.

In the field, approximately 6,000 panicle rows were planted in 2021, wherein 4,000 were planted in Puerto Rico and 2,000 in the RREC for conventional, Clearfield, and Provisia.

Practical Applications

Increasing the number of entries and early generation testing improves the probability of finding the best lines that would have been discarded early in the breeding cycle. The selected lines can move to advanced yield trials and simultaneously be advanced as the panicle rows. This will reduce the waiting time to generate a stable line which ultimately speeds up the breeding process and the release of a new variety.

Acknowledgments

The authors appreciate the financial support of the rice producers of Arkansas through monies administered by the Arkansas Rice Research and Promotion Board. Support is also provided by the University of Arkansas System Division of Agriculture.

Table 1. Yield, days to heading, height, % lodging, and milling yield (total/head) of the top ten conventional long-grain lines and Diamond check in the 2021 Advance Yield Trial (AYT) conducted at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC) at Stuttgart, Arkansas.

Entry	Yield†		Heading† days		Height	Lodging	Milling yield total†		Milling yield head†		Rank yield
	(bu./ac)				(cm)	(%)					
STG18L-250	266	a	102	a-j	112	0%	70	a-h	53	b-l	1
16AR1010	266	a	96	j-m	108	17%	69	c-l	45	m-w	2
STG18L-134	261	ab	101	b-l	107	0%	66	n-q	43	s-x	3
18AR1145	260	abc	99	e-m	115	0%	69	f-n	52	b-p	4
20AR1149	259	a-d	100	d-l	107	0%	69	f-n	54	b-l	5
STG17L-142	259	a-e	100	b-l	102	0%	72	a	51	b-q	6
19AR1177	258	a-e	97	g-m	122	0%	68	g-o	50	c-t	7
STG16L-037	258	a-e	105	a-f	108	0%	66	l-q	47	j-w	8
STG18METR-04	257	a-e	105	a-e	112	0%	67	j-q	47	j-w	9
STG18L-194	254	a-f	105	a-e	113	3%	72	a-d	55	b-i	10
DIAMOND	243	a-g	97	g-m	108	0%	68	g-o	46	l-w	25
Analysis of Variance											
Entry Pr(>F)	3.3e-07**		4.5e-12**		0.4283	0.7543	0.0228*		6.9-e13**		
Rep Pr(>F)	0.9058		0.1924		0.8484	0.7445	0.6363		0.6968		

† Means with the same letter in the same column are not significantly different using Fisher's least significant difference.

* Significant differences at $P \leq 0.05$.

** Highly significant differences at $P \leq 0.01$.

Table 2. Yield, days to heading, height, % lodging, and milling yield (total/head) of top ten conventional long-grain lines and check in 2021 Advance Yield Trial (AYT) conducted at the University of Arkansas System Division of Agriculture's Pine Tree Research Station (PTRS) at Colt, Arkansas.

Entry	Yield†		Heading days	Height	Lodging	Milling yield total†		Milling yield head	Rank yield
	(bu./ac)			(cm)	(%)				
STG17L-205	241	a	106	113	0%	60	n	37	1
STG16L-037	237	ab	103	112	0%	66	a-f	47	2
21AR1201	232	abc	104	109	0%	65	a-k	44	3
STG17L-037	228	a-d	104	108	0%	65	a-l	46	4
20AR1145	227	a-d	104	109	0%	63	f-n	41	5
21AR1041	226	a-e	100	107	0%	65	a-l	37	6
21AR1149	222	a-f	106	113	0%	65	a-i	47	7
LAKAST	222	a-f	101	104	0%	62	g-n	41	8
20AR1153	220	a-g	104	113	0%	62	j-n	41	9
STG17L-079	218	a-h	102	111	0%	67	a-d	51	10
DIAMOND	214	aj	105	110	0%	65	a-h	45	16
Analysis of Variance									
Entry Pr(>F)	0.0011**		0.5504	0.5594	n/a	2.4-e09**		0.0858	
Rep Pr(>F)	0.1415		0.3650	0.5527	n/a	0.2644		0.9266	

† Means with the same letter in the same column are not significantly different using Fisher's least significant difference.

** Highly significant differences at $P \leq 0.01$.

Table 3. Yield, days to heading, height, % lodging, and milling yield (total/head) of top ten conventional long-grain lines in 2021 Stuttgart Initial Trial A (SIT-A) conducted at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC) at Stuttgart, Arkansas.

Entry	Yield†		Heading days	Height	Lodging	Milling yield total†		Milling yield head†		Rank yield
	(bu./ac)			(cm)	(%)					
STG19L-171	293	a	95	111	0%	70	a-i	48	b-p	1
STG19L-136	289	ab	104	119	0%	71	a-f	52	a-h	2
STG19L-184	281	abc	99	118	0%	70	a-i	50	a-m	3
STG19L-070	276	a-d	101	117	0%	70	a-m	42	p-t	4
DIAMOND	275	a-e	95	106	0%	69	a-p	47	d-r	5
STG18L-106	272	a-f	95	108	0%	70	a-k	45	g-r	6
STG19L-097	267	a-g	99	112	0%	71	a-e	52	a-g	7
STG18L-148	267	b-h	100	120	0%	69	b-p	47	c-q	8
STG19L-292	265	b-h	97	118	0%	69	a-m	48	b-p	9
STG19L-275	265	b-i	92	116	0%	68	d-r	46	g-r	10
Analysis of Variance										
Entry Pr(>F)	<2e-16**		0.0061**	0.4708	0.8944	1.5e-06**		5.4e-05**		
Rep Pr(>F)	0.0586		0.0005**	0.8911	0.5877	0.4266		0.5334		

† Means with the same letter in the same column are not significantly different using Fisher's least significant difference.

** Highly significant differences at $P \leq 0.01$.

Table 4. Yield, days to heading, height, % lodging, and milling yield (total/head) of top ten conventional long-grain lines and check in 2021 Stuttgart Initial Trial B (SIT-B) conducted at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC) at Stuttgart, Arkansas.

Entry	Yield[†]		Heading days	Height	Lodging	Milling yield total[†]		Milling yield head[†]		Rank yield
	(bu./ac)			(cm)	(%)					
STG20L-072	264	a	97	105	0%	69	a-d	47	c-s	1
STG20L-243	252	ab	96	107	0%	67	a-r	31	E-H	2
STG20L-022	252	ab	93	112	28%	68	a-j	42	h-D	3
STG20L-264	251	ab	92	110	0%	67	a-s	38	s-F	4
STG20L-196	250	abc	99	109	0%	65	h-y	43	g-C	5
STG20L-085	250	abc	104	111	0%	66	a-v	45	e-x	6
STG20L-011	250	a-d	102	117	0%	68	a-n	49	a-n	7
STG20L-042	250	a-d	99	109	0%	69	abc	47	c-r	8
STG20L-019	249	a-d	95	112	0%	67	a-s	42	i-D	9
STG20L-019	249	a-e	99	112	13%	68	a-i	43	g-C	10
DIAMOND	239	b-g	95	112	0%	67	a-s	42	g-C	21
Analysis of Variance										
Entry Pr(>F)	<2.2e-16**		0.9335	0.0007**	0.2752	<2e-16**		<2e-16**		
Rep Pr(>F)	2.9e-06**		0.6102	0.5423	0.5056	0.2102		0.5966		

[†] Means with the same letter in the same column are not significantly different using Fisher's least significant difference.

** Highly significant differences at $P \leq 0.01$.

Table 5. Yield, days to heading, height, % lodging, and milling yield (total/head) of top ten Clearfield long-grain lines and checks in 2021 Clearfield Advance Yield Trial (IMI-AYT) conducted at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC) at Stuttgart, Arkansas.

Entry	Yield[†]		Heading days	Height	Lodging	Milling yield total[†]		Milling yield head[†]		Rank yield
	(bu./ac)			(cm)	(%)					
20AR1093 (CLL18)	268	a	98	113	0%	68	a-i	50	a-n	1
STG18IMI-176	264	ab	99	121	0%	64	n-q	44	h-r	2
21AR1181	263	abc	96	114	0%	65	k-p	43	k-r	3
STG18IMI-126	262	a-d	97	121	0%	66	g-o	45	g-q	4
20AR1193	260	a-e	96	103	0%	68	a-i	56	abc	5
21AR1073	258	a-f	96	103	0%	69	a-h	56	ab	6
STG19IMI-299	256	a-g	98	116	0%	68	a-l	53	a-h	7
RU1801145	249	a-h	97	116	0%	68	a-j	52	a-l	8
STG17-IMI-73	248	a-i	97	109	0%	69	a-h	50	a-n	9
21AR1177	248	a-j	97	111	0%	67	a-m	53	a-j	10
STG18IMI-383	248	a-j	97	103	0%	66	e-o	52	a-k	11
CLL16	243	b-k	100	112	0%	62	q	39	qrs	13
CL111	215	q-w	90	106	0%	63	pq	40	qrs	14
CL172	204	wx	96	98	0%	66	h-p	49	a-p	15
Analysis of Variance										
Entry Pr(>F)	<2e-16**		0.1040	0.1850	n/a	8.7e-9**		5.4e-8**		
Rep Pr(>F)	0.3171		3.0e-6**	0.3680	n/a	0.4210		0.2570		

[†] Means with the same letter in the same column are not significantly different using Fisher's least significant difference.

** Highly significant differences at $P \leq 0.01$.

Table 6. Yield, days to heading, height, % lodging, and milling yield (total/head) of top ten Clearfield long-grain lines and checks in 2021 Clearfield Stuttgart Initial Trial (IMI-SIT) conducted at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC) at Stuttgart, Arkansas.

Entry	Yield†		Heading days	Height	Lodging	Milling yield total†		Milling yield head†		Rank yield
	(bu./ac)			(cm)	(%)					
STG20IMI-376	282	a	94	126	15%	68	h-I	45	p-G	1
STG20IMI-141	279	ab	92	122	23%	69	a-D	41	B-J	2
STG20IMI-181	275	abc	97	105	0%	68	p-I	41	A-J	3
STG20IMI-289	272	a-d	100	113	0%	70	a-y	53	a-s	4
STG20IMI-215	272	a-e	96	123	0%	68	r-I	46	m-G	5
STG20IMI-239	271	a-f	98	114	0%	68	f-H	50	d-y	6
STG20IMI-101	269	a-g	101	121	0%	71	a-f	57	a-d	7
CLL16	268	a-h	100	118	0%	67	u-J	48	i-D	8
STG20IMI-254	268	a-i	97	126	78%	69	a-B	52	b-w	9
STG20IMI-188	268	a-i	97	125	37%	72	ab	55	a-l	10
STG20IMI-254	268	a-j	100	122	0%	68	m-I	50	d-z	11
CL111	238	z	93	110	0%	69	a-D	50	d-y	109
CL172	218	z	99	104	0%	69	a-D	56	a-j	162
Analysis of Variance										
Entry Pr(>F)	<2e-16**		0.5510	0.1479	0.4397	1.3e-13**		0.0007**		
Rep Pr(>F)	0.7738		2.0e-7**	0.1905	0.6218	0.2517		0.1370		

† Means with the same letter in the same column are not significantly different using Fisher's least significant difference.

** Highly significant differences at $P \leq 0.01$.

Table 7. Yield, days to heading, height, % lodging, and milling yield (total/head) of top ten Provisia long-grain lines in 2021 Provisia Stuttgart Initial Trial (Prov-SIT) conducted at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC) at Stuttgart, Arkansas.

Entry	Yield[†]		Heading days	Height	Lodging	Milling yield total	Milling yield head	Rank yield
	(bu./ac)			(cm)	(%)			
STG20PR-003	180	a	78	97	0%	66	47	1
STG20PR-089	178	ab	80	87	0%	66	45	2
STG20PR-060	172	abc	78	103	0%	63	43	3
STG20PR-054	165	a-e	79	89	0%	63	41	4
STG20PR-004	161	b-f	79	117	0%	63	44	5
STG20PR-079	159	c-g	78	108	0%	67	46	6
STG20PR-045	158	c-g	90	99	0%	66	49	7
STG20PR-085	152	e-i	80	110	0%	66	49	8
STG20PR-032	151	e-j	85	108	0%	63	44	9
STG20PR-022	150	e-k	78	100	0%	59	38	10
PVL02	146	f-l	77	98	0%	67	47	14
Analysis of Variance								
Entry Pr(>F)	<2e-16**		0.5209	0.4134	n/a	0.8337	0.8918	
Rep Pr(>F)	0.0590		0.3489	0.5670	n/a	0.9564	0.9775	

[†] Means with the same letter in the same column are not significantly different using Fisher's least significant difference.

** Highly significant differences at $P \leq 0.01$.

Development of Aromatic Rice Variety in Arkansas

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Abstract

Overall rice acreage in the United States is declining while imports have been rising since the 1980s. Rice imports are mainly driven by the consumption of Jasmine type "aromatic" rice. The aromatic rice breeding program at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC) is actively developing aromatic varieties that not only have good cooking quality and aroma but also have improved agronomic performance and adaptation to the climatic conditions in the mid-South. In 2021, 20 out of 68 entries had a significantly higher yield than the check varieties in the Stuttgart Initial Test. In the Advanced Yield Trial conducted at the RREC, 23 out of 40 entries had a significantly higher yield over the check varieties. The top 3 entries in both trials had a yield advantage of 50 bu./ac or more over Jazzman 2 or ARoma 17. Furthermore, the Uniform Regional Rice Nursery (URRN) conducted in Arkansas showed the three new aromatic lines also out-yielded the check ARoma 17. Our results showed our current selections of the top elite lines have improved the agronomic performance and can be further tested in multi-environment trials.

Introduction

The demand for aromatic rice is increasing in the United States. U.S. rice imports from the 1980s have grown from zero to over 1.1 million metric tons (MMT) (Ehmke and Hamilton, 2021). Of the 51% total long-grain rice imports classified as "fragrant" rice, 16% are basmati and 35% are Jasmine type. The majority of the Jasmine type rice was imported from Thailand. From August through November of 2021, Thailand shipped 155,238 tons of rice that were mostly aromatic (Childs and LeBeau, 2022). As U.S. rice acreage continues to shrink, the demand for aromatic rice continues to increase, likely driven by the non-ethnic consumer base as well as consumers who explore new products and enjoy the "farm to table" experience. The first aromatic rice released from Arkansas was Jes in 2009, followed by ARoma 17 in 2018. ARoma 17 offers exceptional rough rice and milling yields and is adapted to the Arkansas conditions. Further improvement is necessary by expanding the breeding effort of aromatic rice to meet the demands of consumers in the United States.

Procedures

The University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC) works to improve and develop new aromatic rice lines through crossing and selection. In 2021, 48 carefully selected crosses were made to improve agronomic traits such as yield, plant type, disease resistance, as well as good grain quality characteristics and aroma. Sixteen elite lines are crossed to conventional long-grain, 29 to Clearfield long-grain, and 3 to Provisia long-grain lines.

Two yield trials were conducted at the RREC: the Advanced Aromatic Yield Trial (AROAYT) and the Stuttgart Initial Aromatic Trial (AROSIT). The AROAYT of 40 entries was laid out in a randomized complete block design (RCBD) with three replications. The plot size is 12 ft by 3.75 ft with 6 rows at a seeding rate of 70 lb/ac. In AROSIT, there were 68 entries with 3 replications in a RCBD. The length of the plot is 8 ft, with the same width and seeding rate as the AYT. Two additional plots per entry were grown as seed increase for AROAYT, while one additional plot was grown for AROSIT. The total plots for both trials, including seed increase, is 472. Analysis of variance (ANOVA) using R was used to detect significant differences in the test. Additionally, Fisher's least significant difference was used to run multiple comparisons of the entries.

Results and Discussion

Twenty-three entries in the AROAYT had a statistically significant yield advantage over checks ARoma 17 and Jazzman 2 (Table 1). The top three entries with the highest yield in the AYT are STG17-144, STG19-531, and STG17-145, with grain yields of 256, 251, and 241 bu./ac, and milling yields (%whole kernel/ %total milled rice) of 35/63, 52/68 and 44/66, respectively. The days to 50% heading of STG17-144, STG19-531, and STG17-145 are 103, 98, and 104, respectively. All entries exhibited delayed

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heading due to the cold spell experienced during the booting stage. In comparison, ARoma 17 and Jazzman 2 have a yield of 182 and 162 bu./ac and milling yields of 53/66 and 48/65, respectively. The heading date for ARoma 17 is 100 days, and for Jazzman 2, 98 days. The height of experimental lines is mostly a few inches taller than Jazzman 2 or ARoma 17; however, only one entry lodged.

In the Aromatic Stuttgart Initial Test (AROSIT), 20 out of 68 entries yielded significantly higher than ARoma 17 and Jazzman 2 (Table 2). The top three entries are STG20-356, STG20-359, and STG20-361, with yields of 242, 242, and 240 bu./ac and milling yields of 45/64, 47/66, and 47/65, respectively. In comparison, ARoma 17 and Jazzman 2 yielded 181 and 157 bu./ac, with a milling yield of 53/66 and 48/65, respectively. The days to 50% heading of the top three entries are 101, 100, and 100, respectively, which are similar to ARoma 17 but 1–2 days later than Jazzman 2. Lodging was observed in 8 entries in the AROSIT test with an average of 3% to 67%. Overall, the top entries in both AROAYT and AROSIT have a yield advantage of more than 50 bu./ac over the checks ARoma 17 and Jazzman 2.

In addition, 6 aromatic entries were entered in the uniform regional rice nursery (URRN) from the aromatic rice breeding program. In the Arkansas location, 3 entries out-yielded ARoma 17. The lines are AAES1208, AAES1109, and AAES1105 with 238, 232, and 209 bu./ac, respectively, compared to ARoma 17 (203 bu./ac). ARoma 17 had a higher milling yield (65/69) compared to the AAES1208 (62/67), AAES1109 (61/67), and AAES1105 (57/68).

Practical Applications

With the increasing demand for jasmine/aromatic type rice in the United States, the breeding program will have to be competitive to respond to the demands of producers and consumers. We have increased the number of populations and testing of new lines to provide rice producers in Arkansas and the mid-South new and improved high-yielding varieties without compromising the cooking quality and aroma.

Acknowledgments

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Literature Cited

Childs, N. and B. LeBeau. 2022. Rice Outlook: January 2022. Available at: https://www.ers.usda.gov/webdocs/outlooks/103052/rcs-22a.pdf?v=9533.6

Emhke, T. and M. Hamilton. 2021. Fragrant Rice: Opportunity of Risk for U.S. Rice industry? Available at: https://www.cobank.com/documents/7714906/7715347/KED-Report-FragrantRice-Sept2021.pdf/0d45d598-b379-5cec-d6ea-7e09ed53e3a3?t=1631653268813

Table 1. Yield, days to 50% heading, height, %lodging and milling yield (total/head) of aromatic rice lines in the 2021 Aromatic Advanced Yield Trial (AROAYT) conducted at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC) near Stuttgart, Arkansas.

Entry	Yield†		Heading	Height	Lodging†		Milling yield total	Milling yield head	Rank yield
	(bu./ac)		(days)	(cm)	(%)				
STG17-144	256	a	103	120	0%	b	63	35	1
STG19-531	251	ab	98	110	0%	b	68	52	2
STG17-145	241	abc	104	126	0%	b	66	42	3
STG19-332	237	bcd	99	125	0%	b	66	52	4
STG18-365	231	cde	100	118	0%	b	67	48	5
STG19-347	230	c-f	100	127	0%	b	66	47	6
STG19-350	227	c-g	100	117	0%	b	67	49	7
STG19-533	223	c-h	98	114	0%	b	67	50	8
STG19-438	220	d-i	101	121	0%	b	66	49	9
STG19-315	220	d-i	98	122	0%	b	67	49	10
STG19-330	216	e-j	100	122	0%	b	63	49	11
STG19-435	216	e-k	101	119	0%	b	66	48	12
STG19-315	214	e-l	102	119	0%	b	65	49	13
STG19-427	212	f-m	99	124	0%	b	66	48	14
STG19-305	210	g-n	104	124	0%	b	68	53	15
STG19-456	209	g-n	99	103	0%	b	63	47	16
STG19-373	207	h-n	101	113	0%	b	68	55	17
STG19-313	207	h-n	101	120	0%	b	67	53	18
STG19-457	206	h-n	101	107	0%	b	64	50	19
STG19-375	206	h-n	101	109	0%	b	66	50	20
STG19-341	205	h-n	100	120	0%	b	67	46	21
STG19-083	204	i-o	100	112	0%	b	67	51	22
STG17-002	203	i-o	99	113	0%	b	66	48	23
STG18-318	198	j-p	103	118	0%	b	65	50	24
STG18-413	197	k-q	102	108	0%	b	67	43	25
STG19-415	195	l-r	105	117	0%	b	65	50	26
STG19-405	195	l-r	102	130	0%	b	66	54	27
STG19-343	194	m-r	100	112	0%	b	67	48	28
STG18-385	194	m-r	103	116	0%	b	67	51	29
STG19-413	193	m-r	105	114	0%	b	64	47	30
AAES1206	192	n-r	102	103	0%	b	64	44	31
STG19-576	186	o-r	102	99	0%	b	61	41	32
DELLA 2	185	o-r	102	112	0%	b	64	47	33
STG19-323	183	pqr	105	115	0%	b	67	52	34
ARoma 17	182	pqr	100	108	0%	b	66	53	35

Continued

Table 1. Continued

Entry	Yield†		Heading	Height	Lodging†		Milling yield total	Milling yield head	Rank yield
	(bu./ac)		(days)	(cm)	(%)				
STG17-204	181	pqr	103	122	37%	a	67	54	36
AAES1231	179	qrs	97	114	0%	b	65	47	37
STG19-259	177	rs	103	103	0%	b	65	51	38
Jazzman2	162	st	99	94	0%	b	65	48	39
STG196-408	151	t	99	110	0%	b	66	51	40
Analysis of Variance									
Entry Pr(>F)	< 2e-16 **		0.1217	0.5678	0.0204 *		0.7287	0.195	
Rep Pr(>F)	0.02811 *		0.2945	0.6784	0.5366		0.5393	0.2535	

† Means with the same letter in the same column are not significantly different using Fisher's least significant difference.

* Significant differences at $P \leq 0.05$.

** Highly significant differences at $P \leq 0.01$.

Table 2. Yield, days to 50% heading, height, %lodging and milling yield (total/head) of top 10 selected aromatic rice lines and checks in the 2021 Aromatic Stuttgart Initial Test (AROSIT) conducted at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC) near Stuttgart, Arkansas.

Entry	Yield†		Heading	Height	Lodging†		Milling yield total†		Milling yield head†		Rank yield
	(bu./ac)		(days)	(cm)	(%)						
STG20-356	242	ab	101	114	0%	e	64	q-x	45	f-s	1
STG20-359	242	ab	100	110	0%	e	66	e-o	47	a-o	2
STG20-361	240	abc	100	110	0%	e	65	i-t	47	b-p	3
STG20-358	232	a-d	98	106	0%	e	66	d-n	48	a-n	4
STG20-409	229	b-e	101	116	0%	e	67	b-j	53	a	5
STG20-418	222	b-f	103	121	0%	e	61	y	40	q-t	6
STG19-150	220	c-g	100	101	0%	e	65	i-s	45	e-q	7
STG18-391	219	d-g	99	116	0%	e	69	a	52	ab	8
STG20-421	216	d-h	98	101	0%	e	63	wx	44	j-t	9
STG19-083	212	d-h	94	113	30%	b	67	a-e	50	a-h	10
ARoma 17	181	l-t	100	121	0%	e	67	a-f	53	a	40
DELLA 2	181	m-t	99	110	0%	e	64	m-v	45	h-t	41
Jazzman2	157	u-x	99	103	0%	e	63	q-x	45	f-r	54
Analysis of Variance											
Entry Pr(>F)	<2e-16 **		0.07304	0.55624	1.99e-10**		<2e-16**		<2e-16**		
Rep Pr(>F)	0.6738		0.01281 *	0.08414	0.636		0.1221		0.6996		

† Means with the same letter in the same column are not significantly different using Fisher's least significant difference.

* Significant differences at $P \leq 0.05$.

** Highly significant differences at $P \leq 0.01$.

Progress in the Development of Arkansas Lines with High Night Temperature Tolerance

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Abstract

In this report, we present our breeding progress for developing high nighttime temperature (HNT) tolerant lines. A total of 2522 rows of progenies ranging from F_2 to F_6 and derived from crosses between Arkansas cultivars and N22 (a stable medium-grain, very tall, thin-stalked, and HNT tolerant cultivar) were primarily evaluated for plant stature. Previously identified 243 lines with short statures (<130 cm) were also evaluated for milling yields and kernel chalk. For those derived from single crosses Diamond/N22, Zhe733/N22, CLL15/N22, RU1601121/N22, CL53/N22, and Roy J/N22, 720 lines exhibited shorter heights, and among them, 76 also showed acceptable phenotypes (short stature, better straw strength, erect leaves, longer panicles, and diseases free leaves). Of the 243 short-statured lines, 12 lines that showed longer seed length, acceptable milling, and low kernel chalk were identified. Our results indicated that breeding HNT tolerant long-grain rice from a single cross involving N22 is very challenging, but we are optimistic that our backcross and three-way crosses would improve the chance of success. Nevertheless, the selected lines provided major improvements to the undesirable traits of N22. From F_2 populations of backcross Diamond//Diamond/N22 and three-way crosses Kaybonnet//Diamond/N22 and Kaybonnet//Zhe733/N22, 902 F_2 plants were selected. Selected lines will be further screened under controlled HNT conditions to confirm their tolerance, and tolerant lines could serve as pre-breeding germplasm or varieties depending on the quality and agronomic performance in multi-location yield tests.

Introduction

The detrimental effect of high nighttime temperature (HNT) on grain yield and quality is well documented, particularly when it coincides with the heat-sensitive reproductive stages of rice. The decline in the number of filled spikelets (leading to significant yield loss), increased chalkiness, and decreased head rice yields are the manifestations of HNT susceptibility (Counce et al., 2005; Mohammed and Tarpley, 2009).

For several years, we have used controlled growth chambers to evaluate the HNT tolerance of major Arkansas cultivars, both current and old, as well as advanced lines in the pipeline of the University of Arkansas System Division of Agriculture's Rice Breeding Programs (Esguerra et al., 2020; 2021). Most of the cultivars screened have shown high susceptibility to HNT, although some have shown some degree of tolerance (Esguerra et al., 2021). Diamond, the high-yielding and most widely grown long-grain pure-line rice cultivar in Arkansas, is extremely susceptible to HNT in both yield and quality, while Kaybonnet appears to show some degree of tolerance in terms of grain quality under the HNT condition. To date, we have not found any cultivar that could match the HNT tolerance (measured by stable yield and quality under HNT) of N22, a very tall, thin-stemmed, medium-grain, *aus* cultivar from India. Despite multiple reports of HNT susceptibility of U.S. rice cultivars (Counce et al., 2005; Mohammed and Tarpley, 2009; Hardke, 2016), the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC) is the only institution (based from our knowledge) in the U.S. conducting breeding and making concrete progress in developing lines with HNT tolerance.

As early as 2016, Dr. Xueyan Sha had already made four single crosses with N22, and these were RU1601111 (now known as CLL15)/N22, RU1601121/N22, CL153/ N22, and Roy J/ N22). With the goal of developing HNT tolerant lines and mapping populations to find quantitative trait locus (QTL) associated with HNT tolerance/susceptibility, our HNT team, based on our field and chamber results, made three single crosses Diamond/N22, Zhe 733/N22 and Kaybonnet/N22, one backcross Diamond//N22/ Diamond and two three-way crosses Kaybonnet//Zhe 733/N22 and Kaybonnet//Diamond/N22.

This report aims to document the progress on the breeding and selections for the HNT tolerance, describe our observations for each cross population, and present lines that showed potential both in terms of acceptable agronomic phenotype and grain quality.

Procedures

In summer 2021, we planted a total of 2522 rows of advanced lines from F_2 to F_6 generations of crosses between adapted Arkansas germplasm and N22 (Table 1) at the RREC in Stuttgart, Arkansas. Planting was conducted on 27 May 2021 using a drill planter, with each row having approximately 20–25 seeds. Row length is about 5 ft spaced 7.5 in. apart. In 2020, our team identified 243 lines showing short plant heights derived from crosses developed by Dr. Xueyan Sha; these lines were planted in three-row plots for closer agronomic evaluation and assessment of grain quality. The F_2 seeds from crosses Diamond/N22/Diamond, Kaybonnet//Diamond/N22, Kaybonnet//Zhe/N22, and Kaybonnet/N22 were planted in 65,125, 33, and 36 rows, respectively.

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All remaining lines were planted in a single row. A single preflood application of approximately 130 lb/ac of nitrogen in the form of urea was applied to the dry soil surface at V4 to V5 stage, followed by a permanent flood 1 to 2 days later. Weed management was accomplished through chemical herbicides. Rice stink bugs (*Oebalus pugnax*) were the major insect pest controlled and were likewise managed through chemical control (lambda-cyhalothrin). Selections of promising lines were conducted during the late vegetative stage and during the course of the reproductive stage. To be included in the selection, the line must primarily show stand uniformity and short stature (height not exceeding 130 cm from ground to the tip of the panicle). Other traits such as better straw strength, erect leaves, longer panicles, and disease-free leaves were also considered in the selection process.

For the 243 lines planted in 3-row plots, the maturity measured by the number of days from emergence to 50% heading was recorded on a plot basis. Selected lines from the 243 lines were milled to obtain data on milling yield and chalk incidence. Rough rice for milling was first dried using a temperature/humidity-controlled chamber until moisture content reached 11.5–12.5%. A 100-g sample was milled using the Zacarria Sample Mill (CRZ, Zaccaria, Anna, Texas), and the percentages of total milled (TMY) and head rice yield (HRY) were determined. For percentage chalk and seed dimensions, data were obtained by scanning two subsamples of 15-g head rice of each selected line using a SeedCount Image Analyser (SeedCount SC5000TR, Next instrument Pty Ltd., Condell Park, NSW, Australia). Both degree of endosperm chalk (DEC) and percentage grains with chalk (PGWC) were noted. The DEC refers to the percentage total of chalk area over the overall total area of the seeds scanned, while PGWC is the percentage of grains with 50% or more chalked area on its milled kernel.

Results and Discussion

High Nighttime temperature tolerance, as manifested by stable yield and grain quality, are quantitative traits that can only be effectively assessed using plot data or data taken from several plants. Together with the inherent space-limitation of controlled chambers, screening a large number of lines for HNT tolerance poses a great challenge. In response, we decided to advance our crosses in the field and select lines that showed acceptable agronomic phenotype, milling, and grain quality. These selected lines are the ones that will be screened for HNT tolerance inside the growth chambers. This will then reduce the number of lines to be screened, avoid unnecessary screenings of lines with inferior agronomic and grain quality traits, and ultimately make HNT rice breeding more efficient.

In 2021, a total of 2522 rows of progenies from 10 unique crosses between adapted Arkansas germplasm and N22 were grown in the field (Table 1). Of these, 2263 lines of F_3 to F_6 generations were derived from single crosses. Diamond/N22 and Zhe 733/N22 crosses generated the greatest number of progenies of 694 and 400, respectively. Four crosses were in F_2 generations, including single cross Kaybonnet/N22, backcross Diamond//Diamon/N22, and three-way crosses Kaybonnet//Diamond/N22 and Kaybonnet //Zhe 733/N22. On average, with the exception of crosses in their F_2s, around 97–99% of the planted lines have shown good germination and were successfully grown and harvested. The F_2s were selected on a plant basis, with the Kaybonnet//Diamond/N22 cross having the highest selected number of plants at about 425. The F_2 plants from Kaybonnet/N22 cross were generally very tall and had experienced severe lodging; hence no plant was selected.

The major disadvantage of N22 crosses was the abundance of tall phenotypes (heights exceeding 150 cm), which is an undesirable trait associated with high lodging susceptibility in rice. Therefore, our first goal is to select for lines showing short statures. Among our crosses, CLL15/N22 produced the highest number of short-statured lines at about 52%, followed closely by RU1601121/N22 and CL153/N22, both having 47% (Table 1). Diamond/N22 and Zhe 733/N22 lines had the least number of short stature lines with 16% and 19%, respectively. Upon close inspection of these short lines, we have also noted those lines exhibiting acceptable agronomic characteristics, including better straw strength, erect leaves, longer panicles, and disease-free leaves. A total of 76 lines have displayed acceptable phenotypes. This result highlights the drawback that crossing a released cultivar with an exotic germplasm will lead to undesirable phenotypes; therefore, rigorous selections are necessary for the introgression of the traits of interest and developing desirable cultivars. This phenomenon was already noticeable during the early stages of selection on the single crosses; thus, we developed a backcross and three-way crosses to further improve the phenotypes of the lines. Overall, we have selected 902 plants showing good agronomic potential from our backcross and three-way crosses. We are hoping that these lines, which will be planted in F_3 rows next season, will have more improved phenotypes than the single crosses we have planted in the field this year.

In 2020, we identified 243 short stature lines from crosses between N22 and adapted cultivars CLL15, CL153, RU1601121, and Roy J, which were initially developed by Dr. Xueyan Sha. In 2021, we planted these lines in 3-row plots for further phenotypic characterizations and milling analysis. Eighty-seven of these lines were harvested based on selections of erect plant architecture and/or good panicle characteristics. The 12 lines presented in Table 2 showed longer kernel lengths, acceptable milling, and low chalk values. Medium-grain lines with acceptable phenotypes, milling, and chalk were also identified. Because our previous results (Esguerra et al., 2020) indicated that medium-grain cultivars had shown HNT yield tolerance, we have focused on improving long-grain cultivars. The heading days of 12 selected lines ranged from 77 to 102 days. Nine of the lines were selected from RU1601121/N22 cross, followed by 2 and 1 line from Roy J/N22 and CLL15/N22 cross, respectively. In our previous report (Esguerra et al., 2021), we reported RU1601121 as one of the cultivars showing minimal increase in chalk under HNT conditions, thus a cross between this line and N22 may have a higher probability of producing HNT tolerance progenies. Notably, no lines were selected from CL153/N22 cross. Overall, the selected lines showed acceptable milling (TMY: 69–75%; HRY: 57–65%) and low chalk values (DEC: 0.20–2.23%; PGWC: 0.63–3.66%). Line 21RN214 had the lowest chalk value (DEC:0.2%; PGWC: 0.63%), while 21RN215 had the highest milling yields (TMY:75%; HRY:65%). In terms of seed dimension, all lines have shown shorter seed length (6.11–6.85 mm), wider seed width (2.35–2.6), and thinner seed thickness (2.17–2.39 mm) compared to Diamond. To be classified as long-grain rice, seed length should measure 6.61 mm or longer and seed length by width ratio should be 3.00 or greater (Adair et al., 1972). Based on this classification, the majority of the 12 selected will fall short of being categorized as long grain. These observations suggest that among the traits important to rice breeders, having acceptable long-grain seed dimensions from a single cross with N22 is the most challenging. We are hoping that, with our current backcross and three-way crosses, we will be able to select a typical long-grain rice line for its seed dimensions. Nevertheless, the selected lines presented are still a major improvement to the medium grain size, thin culms, and very tall height of N22. These lines will be our priority entries for our HNT screening using controlled chambers for 2022. Lines that showed tolerance to HNT will be analyzed for amylose content and gelatinization temperature, be crossed with other adapted Arkansas cultivars, and may also be entered into yield trials conducted in the station.

Practical Applications

The selected lines in this experiment will be used as either an HNT tolerant breeding material or may also be released as a variety if they pass the multi-location yield trials. The F_4 lines derived from Diamond/N22 and Zhe 733/N22 crosses that are currently being grown in the greenhouse will primarily be used to identify QTLs associated with HNT tolerance but may also be used for mapping other important breeding traits such as plant height, presence/absence of awn, seed size, and other important agronomic traits.

Acknowledgments

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Literature Cited

Adair, C.R., C.N. Bollich, D.H. Bowman, N.E. Jodon, T.H. Johnston, B.D. Webb, and J.G. Atkins. 1972. Rice breeding and testing methods in the United States *In*: Rice in the United States: Varieties and production. USDA-ARS Agric. Handb. 289. US Gov. Print. Office, Washington, DC. p. 25–75.

Counce, P.A., R.J. Bryant, C.J. Bergman, R.C. Bautista, Y.J. Wang, T.J. Siebenmorgen, K.A.K. Moldenhauer and J.F.C. Meullenet. 2005. Rice milling quality, grain dimensions, and starch branching as affected by high night temperatures. Cereal Chem. 85:645-648.

Esguerra, M.Q., C.C. Hemphill, and P.A. Counce. 2020. Differential Response of Arkansas Rice Varieties on HNT treatments at different reproductive stages. *In*: K.A.K. Moldenhauer, B. Scott, and J. Hardke (eds.) B.R. Wells Arkansas Rice Research Studies 2019. Arkansas Agricultural Experiment Station Research Series 667:34-38. Fayetteville.

Esguerra, M.Q., C.C. Hemphill and P.A. Counce. 2021. Screening for High Night Temperature Tolerance of Popular Arkansas Varieties and Advanced Lines. *In*: J. Hardke, X. Sha, and N. Bateman (eds.) B.R. Wells Arkansas Rice Research Studies 2020. Arkansas Agricultural Experiment Station Research Series 676:41-46. Fayetteville.

Hardke J. 2016. Reviewing the 2016 Arkansas rice Season. Arkansas Row Crops. University of Arkansas, Fayetteville, Ark.

Mohammed, A.R. and L. Tarpley. 2009. Impact of high nighttime temperature on respiration, membrane stability, antioxidant capacity and yield of rice plants. Crop Sci. 49:313-322.

Table 1. List of crosses planted in the summer of 2021 by the High Night Temperature group at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center.

Cross	Total lines planted[a]	Type of cross	Lines harvested[b]	Short stature lines[c]	No. of acceptable phenotype[d]	Harvest generation
Diamond/N22	694	Single	690	110	15	F4
Zhe 733/N22	400	Single	390	74	4	F4
CLL15/N22	322	Single	321	166	10	F5-F7
RU1601121/N22	281	Single	278	133	10	F5-F7
CL153/N22	266	Single	264	127	17	F5-F7
Roy J/N22	300	Single	297	110	20	F5-F7
Kaybonnet/N22	(1)	Single	-	-	-	-
Diamond//Diamond/N22	(8)	Backcross	325	325	*	F3
Kaybonnet//Diamond/N22	(18)	3-Way	425	425	*	F3
Kaybonnet //Zhe 733 /N22	(3)	3-Way	152	152	*	F3

[a] Numbers inside a parenthesis refers to number of populations for each cross.

[b] Due to excessive lodging and very tall heights, Kaybonnet/N22 plants were not harvested. For backcross and 3-way crosses, the numbers refer to the total number of F_3 plants harvested.

[c] Plants having heights not exceeding 130 cm.

[d] Acceptable phenotypes are lines showing short stature, better straw strength, erect leaves, longer panicles, and diseases free leaves, while plants marked with an asterisk (*) were not assessed for acceptability, but all exhibited short stature plant heights ranging from 100–130 cm.

Table 2. N22 single-cross lines showing good agronomic and grain quality potentials that may serve as possible high night temperature tolerant breeding germplasm or varieties.

2021 Line Code	Cross	Heading Days	Generation	Seed Length (SL)	Seed Width (SW)	Grain Thickness	SL/SW Ratio	PGWC[a]	DEC[b]	TMY[c]	HRY[d]
				----------------------(mm)--------------------				---------------------(%)-------------------			
21RN74	RoyJ/N22	77	F7	6.11	2.35	2.39	2.60	0.65	0.76	71.37	55.77
21RN78	RoyJ/N22	83	F7	6.78	2.42	2.31	2.80	2.20	2.73	71.56	60.86
21R113	CLL15/N22	81	F5	6.19	2.46	2.26	2.52	0.40	1.35	70.35	55.01
21R176	RU1601121/N22	76	F5	6.27	2.41	2.31	2.60	1.40	1.66	69.07	59.08
21R177	RU1601121/N22	81	F5	6.57	2.40	2.36	2.74	0.40	0.77	71.71	56.58
21R184	RU1601121/N22	75	F5	6.62	2.42	2.26	2.74	1.60	3.66	71.94	60.15
21R196	RU1601121/N22	102	F5	6.50	2.44	2.33	2.66	0.70	1.25	71.36	56.94
21R205	RU1601121/N22	87	F6	6.79	2.56	2.28	2.65	0.70	1.39	70.36	60.31
21R208	RU1601121/N22	87	F6	6.57	2.35	2.28	2.80	1.20	2.23	71.11	60.05
21R214	RU1601121/N22	91	F7	6.79	2.53	2.37	2.68	0.20	0.63	73.30	64.96
21R215	RU1601121/N22	87	F7	6.85	2.41	2.27	2.84	1.35	1.67	74.73	64.89
21R242	RU1601121/N22	79	F7	6.51	2.60	2.17	2.50	1.60	2.08	71.19	60.42
Diamond	Inbred	85	Pure-line	6.97	2.27	2.40	3.07	0.65	0.90	70.71	59.03

[a] PGWC–percentage grains with chalk, the percentage number of grains with 50% or more chalk on its milled kernel.

[b] DEC–degree of endosperm chalk, the percentage of total chalk area over the overall total area of the seeds scanned.

[c] TMY–total milling yield, percentage of milled rice from rough rice.

[d] HRY–head rice yield, percentage of whole-grain rice after milling of rough rice.

Arkansas Rice Variety Advancement Trials, 2021

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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. The 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 2021. Averaged across locations, grain yields were highest for the conventional long-grain hybrid RT XP753, the FullPage long-grain hybrid RT 7521 FP, the conventional medium-grain RU1901033, the MaxAce long-grain RTv7231 MA, the Clearfield medium-grain RU2101234, the Clearfield long-grain RU2001093, the conventional long-grain RU2001185, and the conventional long-grain RU2001125.

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 2021 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 6 April, 20 May, 19 April, 13 April, 24 March, and 14 May, respectively. Pure-line cultivars (varieties) were drill-seeded at a rate of 33 seed/ft^2 in plots eight 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. Phosphorus and potassium fertilizers were applied before seeding at the RREC, PTRS, and NERREC locations. The PTRS also received an application of zinc.

Nitrogen was applied to ARVAT studies located on experiment stations at the 4- to 5-leaf growth stage in a single preflood application of 125 lb N/ac at RREC, 125 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

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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 the 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 of the study was arranged in a randomized complete block design with four replications.

Results and Discussion

Selected agronomic traits, grain yield, and milling yields for the conventional long-grain trial are shown in Table 1. Twenty-three experimental lines and 2 checks were included. The checks Diamond and RT XP753 averaged 202 and 254 bu./ac, respectively. The experimental lines RU2001185 and RU2001125 averaged 218 bu./ac, notably higher than the Diamond check with similar milling yields.

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 CLL15, CLL16, and RT 7521 FP averaged 212, 214, and 247 bu./ac, respectively. The experimental line RU2001093 averaged 223 bu./ac, notably higher than the CLL15 and CLL16 checks, with similar milling yields.

Selected agronomic traits, grain yield, and milling yields for the conventional and Clearfield medium-grain trial are shown in Table 3. Eight experimental lines and 3 checks were included. The checks Titan, CLM04, and Lynx averaged 210, 196, and 211 bu./ac, respectively. The conventional experimental line RU1901033 averaged 232 bu./ac, notably higher than the Titan and Lynx checks with similar or greater milling yields. The Clearfield experimental line RU2101234 averaged 225 bu./ac, notably higher than the CLM04 check but with lower milling yields.

Selected agronomic traits, grain yield, and milling yields for the conventional and Clearfield long-grain aromatic trial are shown in Table 4. Five experimental lines and 1 check were included. The check ARoma17 averaged 169 bu./ac. The conventional experimental line STG19L-05-330 and the Clearfield experimental line RU2101208 averaged 206 and 211 bu./ac, respectively, with milling yields similar to the Aroma17 check.

Selected agronomic traits, grain yield, and milling yields for the Provisia long-grain trial are shown in Table 5. Four experimental lines and 2 checks were included. The checks PVL03 and RTv7231 MA averaged 196 and 229 bu./ac, respectively. No experimental line outperformed the checks.

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

The authors wish to thank all Arkansas rice growers for financial support of the Arkansas Rice Variety Advancement Trials 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.

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 2021.

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)						
RU2001145	L	95	38	0	59/70	219	160	227	180	195	212	199
RU2001153	L	95	38	0	61/71	228	174	242	179	220	233	212
RU1601010	L	88	38	7	58/70	218	168	237	193	229	210	209
RU2101041	L	94	37	0	57/71	228	174	232	183	216	211	207
RU2101065	L	96	40	0	58/71	225	151	214	160	193	200	190
RU2101141	L	98	40	0	59/71	215	152	214	179	189	196	191
RU2101149	L	99	40	0	59/70	229	177	221	182	213	202	203
RU2101161	L	97	37	4	63/72	229	160	214	153	200	199	194
RU2101193	L	99	40	0	61/70	219	156	210	186	211	194	196
RU2101201	L	95	40	0	59/70	238	203	228	199	219	207	216
RU2101117	L	97	37	0	61/71	229	164	215	173	217	197	199
RU2101197	L	96	38	0	62/70	228	187	230	174	210	196	204
RU2001125	L	92	39	0	59/70	225	182	250	203	215	231	218
RU2001185	L	92	38	2	59/70	236	171	241	210	233	215	218
20SIT0655	L	93	37	0	60/70	241	179	236	197	226	224	217
20SIT0930	L	93	37	0	60/71	228	180	221	176	208	207	203
20SIT0931	L	95	37	0	61/71	227	169	242	190	221	214	210
RU2101137	L	91	38	3	56/70	231	192	242	174	219	224	213
RU2101125	L	95	37	0	59/71	233	178	240	184	220	221	212
LG20-STG-012	L	97	44	11	62/70	210	151	184	158	202	168	181
LG20-STG-014	L	97	43	3	64/71	196	150	182	165	187	173	175
11X185	LH	90	40	44	53/69	201	170	198	189	204	152	186
05X185	LH	90	42	0	54/70	202	165	198	187	203	179	189
Diamond	L	92	37	3	59/70	226	165	238	179	220	194	202
RT XP753	LH	89	37	0	56/71	282	252	263	227	251	249	254
$LSD_{(0.05)}$[c]		1.0	1.0	5.4	1.6/0.4	18.8	29.7	22.0	15.4	16.1	25.2	8.9

[a] Grain type: CL = Clearfield long-grain, CM = Clearfield medium-grain, FLH = FullPage long-grain hybrid, L = conventional long-grain, LH = long-grain hybrid, M = conventional medium-grain, ML = MaxAce long-grain, and 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.

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 2021.

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)	-----------------	-----------------	-----------------
RU1801145	CL	95	40	2	60/70	230	169	245	200	214	226	214
RU1901081	CL	94	39	3	62/71	244	176	236	187	212	230	214
RU2001085	CL	93	36	1	60/70	227	176	229	181	210	230	210
RU2001093	CL	92	38	0	58/69	234	207	248	194	223	237	223
RU2101001	CL	95	39	18	59/70	220	173	220	186	221	188	203
RU2101005	CL	94	37	0	62/71	228	184	219	183	207	210	206
RU2101073	CL	89	33	0	56/71	205	164	214	162	219	213	196
RU2101081	CL	94	37	0	61/72	201	179	214	164	202	228	198
RU2101089	CL	90	33	0	57/71	196	184	194	175	201	227	196
RU2101177	CL	95	38	0	57/68	215	186	240	189	223	239	215
RU2101181	CL	95	39	0	58/69	204	178	230	182	212	219	202
RU2101216	CL	96	39	2	59/70	214	168	240	174	228	226	210
RU2101226	CL	92	38	6	61/71	210	191	232	171	193	215	203
RU1801101	CL	92	35	4	62/70	239	195	231	193	220	232	218
RU1901129	CL	98	35	0	65/71	239	191	212	182	196	208	205
RU2001121	CL	92	34	4	63/71	214	184	202	169	209	221	200
RU2001129	CL	92	33	0	62/70	233	192	229	176	196	233	210
RU2101101	CL	87	33	18	59/69	229	139	235	205	226	166	201
RU2101221	CL	93	36	0	63/70	225	195	211	183	206	216	206
20CAYT09	CL	91	34	0	56/71	195	198	217	170	187	234	200
20CAYT17	CL	89	33	6	58/71	210	207	216	198	238	232	216
21AYT53	PL	87	38	31	47/69	247	126	213	168	168	154	183
RT 7521 FP	FLH	91	39	10	58/70	250	222	244	234	248	289	247
CLL15	CL	91	34	2	60/69	234	198	218	184	206	240	212
CLL16	CL	96	38	0	57/69	241	195	220	180	217	229	214
$LSD_{(0.05)}$[c]		1.1	1.0	6.4	2/1	22.1	38.9	19.8	13.4	13.5	29.1	9.9

[a] Grain type: CL = Clearfield long-grain, CM = Clearfield medium-grain, FLH = FullPage long-grain hybrid, L = conventional long-grain, LH = long-grain hybrid, M = conventional medium-grain, ML = MaxAce long-grain, and 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.

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 2021.

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)						
RU1801238	CM	94	35	9	61/71	224	149	214	185	224	220	208
RU1901137	CM	96	34	0	63/70	232	189	226	197	212	203	210
RU1901033	M	89	32	2	63/71	249	205	238	210	241	246	232
RU1901165	M	92	32	0	65/70	236	201	233	203	225	233	221
RU2001133	M	94	35	4	65/69	224	158	213	192	211	223	203
RU2101234	CM	94	35	0	61/68	245	204	233	204	232	233	225
RU2101113	M	91	35	0	62/70	237	180	223	198	226	224	214
RU2101165	M	92	34	0	64/69	229	168	210	188	207	224	204
Titan	M	88	34	0	59/70	227	202	236	175	221	206	210
CLM04	CM	92	38	8	64/70	213	151	218	165	206	199	196
Lynx	M	94	36	20	62/70	220	166	231	181	234	213	211
$LSD_{(0.05)}$[c]		0.9	0.8	7.7	1.0/0.4	NS	27.3	NS	18.8	11.0	16.9	8.8

[a] Grain type: CL = Clearfield long-grain, CM = Clearfield medium-grain, FLH = FullPage long-grain hybrid, L = conventional long-grain, LH = long-grain hybrid, M = conventional medium-grain, ML = MaxAce long-grain, and 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.

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 2021.

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)						
RU1901206	LA	102	33	0	61/68	--	--	208	159	186	186	184
RU1901231	LA	98	39	0	61/69	--	--	185	141	179	188	172
STG18L-06-413	LA	102	36	0	60/70	--	--	199	150	207	196	188
STG19L-05-330	LA	100	39	0	64/70	--	--	220	178	211	215	206
RU2101208	CLA	102	35	0	63/69	--	--	233	195	221	196	211
Aroma17	LA	100	37	0	64/70	--	--	184	132	181	184	169
$LSD_{(0.05)}$[c]		1.2	1.4	NS	1.4/0.4	--	--	21.3	11.8	14.8	NS	9.2

[a] Grain type: CL = Clearfield long-grain, CLA = Clearfield aromatic, CM = Clearfield medium-grain, FLH = FullPage long-grain hybrid, L = conventional long-grain, LA = long-grain aromatic, LH = long-grain hybrid, M = conventional medium-grain, ML = MaxAce long-grain, and 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.

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 2021.

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)						
21PSIT2001	PL	88	36	0	55/68	--	--	204	160	--	197	187
21PSIT2002	PL	90	33	0	52/69	--	--	207	169	--	184	187
21PSIT2003	PL	87	36	0	51/68	--	--	189	164	--	184	179
21AYT55	PL	86	32	0	55/69	--	--	149	107	--	152	136
RTv7231MA	ML	88	33	0	52/69	--	--	247	206	--	233	229
PVL03	PL	98	35	2	60/70	--	--	225	153	--	216	196
$LSD_{(0.05)}$[c]		2.6	1.4	NS	1.6/0.5	--	--	16.1	21.4	--	24.4	11.1

[a] Grain type: CL = Clearfield long-grain, CM = Clearfield medium-grain, FLH = FullPage long-grain hybrid, L = conventional long-grain, LH = long-grain hybrid, M = conventional medium-grain, ML = MaxAce long-grain, and 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.

Association Mapping Unravels Novel Potential Candidate Genomic Loci Associated with Number of Spikelets and Spikelet Sterility in a Rice *Japonica* Panel under High Nighttime Temperature

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Abstract

In order to dissect the genetic complexity of grain yield (GY) in response to high nighttime temperature (HNT) stress at the reproductive stage, a panel of 81 *Japonica* rice accessions of the USDA Rice Mini-core Collection (URMC) was treated with HNT stress at the R2 and R5 stages. The quantifiable GY components and grain quality traits were analyzed in a correlation analysis to understand the relationship between the multiple grain yield components tested in the panel. Using the phenotyping data for GY components [total number of spikelets per panicle (TSP) and number of un-filled grains per panicle (NUFGP)], a genome-wide association study (GWAS) was conducted using a FarmCPU model with a set of 204K single nucleotide polymorphisms (SNPs), to identify novel genomic loci/SNPs associated with TSP and NUFGP. The association mapping analysis identified 42 novel, highly significant SNPs associated with TSP and 95 novel significant SNPs associated with NUFGP under HNT stress. Out of these SNPs, 9 significant SNPs associated with TSP and 12 significant SNPs associated with NUFGP were co-incident with genomic regions of previously reported quantitative trait loci (QTLs) related to GY under heat stress. These novel potential candidate genomic loci/SNPs have a potential use in SNP-based marker-assisted selection, QTL mapping, pyramiding of genomic regions related to grain yield, and HNT stress tolerance into elite Arkansas rice cultivars.

Introduction

Rice (*Oryza Sativa* L.), one of the most important staple crops, feeds about 50% of the world's population for their primary dietary needs. In recent years, the increase in rice production, attributed to the Green Revolution, has slowed down while the demand for rice production is continuously increasing, with a demand for a doubling of the global rice production by 2050. In order to meet this demand in rice production, the key objective is to develop new management strategies to enhance rice production using plant genomics-assisted breeding of high-yielding rice varieties for multiple environments, in combination with the sustainable use of agricultural inputs. Additionally, the reduction in new available arable lands, limited water availability, and an increase in the frequency of unexpected weather are becoming daunting challenges for food security and sustainability worldwide (Roth et al., 2016).

In the past ten years, a growing number of studies have attempted to quantify the impact of the unprecedented increase in temperatures on rice production. Although most regions worldwide are more integrated into global rice markets than they used to be, and will be even more over the next few decades, it is necessary to evaluate rice production under increasing temperatures at a regional scale (Lobell and Gourdji, 2012). The global mean surface temperature increased rapidly and considerably during the 20th century, and an increase of 0.54–8.64 °F (0.3–4.8 °C) is predicted by the end of the 21st century (Pachauri et al., 2014). Based on recent reports by the Intergovernmental Panel on Climate Change (IPCC), high daytime temperature extremes and warmer nights are likely to become more frequent and intense in the near future. Notably, nighttime temperatures have increased more rapidly than daytime temperatures (Peng et al., 2004).

The rice crop is highly sensitive to high-temperature stress, especially during the reproductive stage, during which high temperature may severely reduce grain yield (GY). An increase of 1.8–7.2 °F (1–4 °C) reduced rice GY by 0–49%; GY decreased 14% for every 1.8 °F (1 °C) increase in temperature (Singh et al., 2009). Peng et al. (2004) reported that an increase of 1.8 °F (1 °C) in nighttime temperature reduced 10% of rice GY. In recent years, high nighttime temperature (HNT) during the reproductive stage of rice is one of the detrimental factors significantly affecting the GY components reducing GY and poor grain filling, leading to poor grain quality under field conditions (Counce et al., 2005), which can be simulated under controlled greenhouse conditions (Kumar et al., 2017). During the early reproductive stage (panicle initiation), HNT stress showed significant reduction in panicle length (PL) and total number of spikelets per panicle (TSP) compared to control conditions studied in a diverse rice panel (Kumar et al., 2021). During the middle (just before anthesis) and late reproductive stages (just after anthesis), HNT stress events reduce

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the grain filling rate causing spikelet sterility (SS) and reduction in grain weight and quality traits (Kumar et al., 2017). So far, HNT stress has been speculated to have a significant impact on panicle number, TSP, spikelet fertility (SF), and grain shape and size (Xu et al., 2020). However, limited information is available on the effects of HNT stress on TSP and SF, which determine the final GY in rice. Xu et al. (2020) reported that TSP and SF are more prone to significant reduction than panicle numbers in rice. Furthermore, optimizing the plant growth during spikelet development is extremely vital to elevate GY under HNT stress.

To understand the basal mechanisms involved in increasing GY and enhancing HNT tolerance, there is a wide range of genetic variation available in the diverse rice populations, including the *Indica* and *Japonica* subpopulations (Kumar et al., 2018). However, the *Japonica* subpopulations interestingly showed the least reduction in the GY components (Kumar et al., 2018, 2019) and higher HNT tolerance compared to *Indica* subpopulations (Kumar et al., 2019), where the identification of favorable alleles for GY components such as PL, TSP, and number of un-filled grains per panicle (NUFGP) are the easiest phenotypes to quantify and could be a useful, practical approach. Several studies have been carried out to map and characterize the genetic variation conferring GY components and heat tolerance to rice under high daytime temperature (HDT) stress (Xu et al., 2020). Nevertheless, very limited results of extensive mapping studies under HNT stress were available until now (Xu et al., 2020, Kumar et al., 2021). Therefore, to unravel potential candidates for genomic loci involved in natural genetic variation for GY components under HNT stress, it is important to initiate a genome-wide scan, using genome-wide association mapping, for further advanced genetic analyses.

In order to identify novel potential candidate genomic loci/SNPs involved in natural genetic variation in the *Japonica* subpopulations under HNT, we initiated a HNT screen of 81 diverse *Japonica* rice accessions of the USDA rice mini-core collection (URMC) and mapped the novel loci/SNPs associated with GY components using genome-wide association mapping. The novel genomic loci/SNPs identified in the pilot study may accelerate the breeding of high-yielding and heat-tolerant rice varieties, using SNP-based marker-assisted selection, for the Arkansas rice-growing areas.

Procedures

Plant Materials and HNT Stress Conditions

A panel of 81 diverse *Japonica* rice accessions from the URMC was screened under HNT stress in the greenhouses in the Rosen Center at the University of Arkansas System Division of Agriculture, Fayetteville. Rice plants with tagged panicles at the R2 (booting stage) and R5 (after anthesis to grain filling) stages were transferred to HNT of 82.4°F (28 °C) until harvesting maturity, while controls were maintained at 71.6 °F (22 °C) with the day temperature of 86°F (30°C). Data loggers (HOBO MX2303) were installed in the greenhouses to monitor and record the temperatures throughout the growth period, which maintained continuous HNT stress during most of the flowering and harvest maturity periods. At harvesting maturity (18–20% moisture), panicles were harvested, air-dried, and used for recording the phenotyping data.

HNT Phenotyping and Data Analysis

After harvesting the individual rice panicles from multiple replications of each genotype, four major tagged panicles of the main stem were taken from each treatment (control and HNT stress treatments at R5 stage) for counting PL, TSP, number of filled grain per panicle (NFGP), NUFGP,100-grain weight (100-GW), and grain quality trait.

For statistical analyses, the analysis of variance, full descriptive statistics, and trait correlation analysis were performed to analyze the phenotypic variation among the diverse *Japonica* rice accessions for grain yield components and quality traits under HNT stress using JMP genomics and R statistical packages. The mean values of TSP and NUFGP of each accession were then used for association mapping.

Genome-Wide Association Mapping

After SNPs detection from the 81 *Japonica* rice genomes with standard quality checks (less than 30% missing rate and more than 5% MAF), a set of best 204,262 SNPs were used for performing genome-wide association mapping using the Fixed and random model Circulating Probability Unification (FarmCPU) tool with multiple loci linear mixed model. The model uses principal components as covariates for finding the significant marker-trait associations. The association threshold was set at $-\log_{10}(p)$ 4.0 to detect the most significant SNPs associated with TSP and NUFGP under HNT stress.

Results and Discussion

To investigate the genetic basis of HNT tolerance in a panel of 81 diverse *Japonica* rice accessions of the URMC, we have analyzed the phenotypic data to study the correlation among grain yield traits PL, TSP, NFGP, NUFGP, 100-GW, and the grain quality trait percent chalkiness (Chalk%) under HNT stress. The Pearson's correlation coefficient suggests that PL is positively correlated with TSP, NUFGP and NFGP, chalk% and 100-GW, while NFGP is positively correlated with TSP and chalk%, showing a negative correlation with UNUFGP and 100-GW (Fig. 1). Interestingly, chalk% is negatively correlated with 100-GW, which suggests that an increase in chalkiness in rice grains reduces grain weight resulting ultimately in grain yield reduction under HNT stress (Fig. 1). The phenotypic data was used to identify the novel genomic loci/or SNPs associated with the 'favorable' grain yield components and 'unfavorable' quality trait (chalk%) in the 81 diverse *Japonica* rice genotypes of the URMC under HNT. For this, association mapping was performed using an advanced tool, termed FarmCPU, with a modified mix linear model (MLM) method and multiple loci linear mix model (MLMM) that incorporates multiple markers simultaneously as covariates in a stepwise MLM to partially remove the confounding between testing markers and kinship. The results of association mapping for TSP and NUFGP in the panel of 81 *Japonica* accessions were plotted in Manhattan plots (Fig. 2), showing the significance level based on the threshold that was set at $-\log_{10}(p)$ 4.0, with all of the most significant associated SNPs found above the thresholds. The association mapping identified 42 novel highly significant SNPs/loci associated with TSP in the *Japonica* panel under HNT stress, and out of these, 31 SNPs/loci showed more than 30% allelic effect for TSP under HNT stress, shown in Table 1. To validate these significant SNPs, we screened and found co-localization of 9 of these significant SNPs within the genomic regions of 6 previously reported QTLs related to grain number (GN) in chr 1, spikelet fertility (SF & SS) on chr 2 & 4, days to flowering (DTF) on chr 8, 10, and 11 in the rice genome (Table 1). For NUFGP, association mapping identified 95 novel highly significant SNPs/ loci under HNT stress, and out of these 31 significant SNPs associated with NUFGP showed more than 29% allelic effect, as shown in Table 2. In support of our association mapping results, we found that 12 highly significant SNPs/loci were found within the regions of 6 previously reported QTLs related to spikelet fertility (SF) in chr 1 & 2, heat tolerance at booting stage (HTB) in chr 2, spikelet sterility per panicle (SSP) in chr 4, heat tolerance and spikelet fertility (HTSF) in chr 5, and heat tolerance under temperature (HTT) in chr 8 in the rice genome (Table 2). These SNPs can be useful for an SNP-based marker-assisted selection for favorable alleles in the U.S./Arkansas rice cultivars, especially in the *tropical japonica* rice germplasm used for QTL mapping, and for identification of candidate genes to dissect biological pathways involved in rice productivity under HNT.

Practical Applications

In this study, we quantified the effects of HNT stress on TSP and NUFGP, and determined the relationship among GY components in a set of *Japonica* rice accessions. Using the phenotyping data, we identified novel potential candidate genomic loci or SNPs associated with TSP and NUFGP using a global association mapping approach under HNT stress. In the association mapping, these SNPs exhibit potential favorable allelic effects on grain yield components in the analysis. Furthermore, in support of our analysis, we found the co-localization of significant SNPs with previously reported QTLs related to grain yield in rice under heat stress. Therefore, the significant SNPs with higher positive allelic effect and co-localized SNPs with previously detected QTLs can be useful in the rice program using SNP-based marker assisted-selection for favorable alleles in the US rice cultivars, especially in the *Japonica* rice, QTL mapping, and enhancing of our understanding of HNT stress mechanism in rice.

Acknowledgments

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Literature Cited

Buu, C.B., P.T. Ha, B.P. Tam, T.T. Nhien, N.V. Hieu, N.T. Phuoc, L.T. Minh, L.H. Giang, and N.T. Lang. 2014. Quantitative trait loci associated with heat tolerance in rice (*Oryza sativa* L.). Plant Breed. Biotech. 2(1):14-24.

Cao Z., Y. Li, H. Tang, B. Zeng, X. Tang, Q. Long, et al. 2020. Fine mapping of the qHTB1-1QTL, which confers heat tolerance at the booting stage, using an *Oryza rufipogon* Griff. introgression line. Theor. Appl. Genet. 133 1161–1175. 10.1007/s00122-020-03539-7.

Counce P.A., R.J. Bryant, C.J. Bergman, R.C. Bautista, Y.J. Wang, T.J. Siebenmorgen, K.A.K. Moldenhauer, and J.F. Meullenet. 2005. Rice milling quality, grain dimensions, and starch branching as affected by high night temperatures. Cereal Chem. 82:645-648.

Kumar A., J. Thomas, S. Yingling, Y. Dwiningsih, V. Ramegowda, J. Gaspar, C, Henry, P. Counce, T.J. Siebenmorgen, K.A.K. Moldenhauer, and A. Pereira. 2017. Screening diverse rice cultivars for heat tolerance and grain quality under high nighttime temperature. *In*: R.J. Norman and K.A.K. Moldenhauer (eds.) B.R. Wells Arkansas Rice Research Studies 2016. Arkansas Agricultural Experiment Station Research Series 643:61-67.

Kumar A., S. Yingling, C. Ruiz, Y. Dwiningsih, C. Gupta, J. Thomas, P. Counce, T.J. Siebenmorgen, K.A.K. Moldenhauer, and A. Pereira. 2019. Screening of *indica* and *japonica* rice subspecies for grain yield and quality under high nighttime temperature. *In*: R.J. Norman and K.A.K. Moldenhauer (eds.) B.R. Wells Arkansas Rice Research Studies 2018. Arkansas Agricultural Experiment Station Research Series 659:61-66.

Kumar A., S. Yingling, J. Thomas, C. Ruiz, Y. Dwiningsih, C. Gupta, P. Counce, T.J. Siebenmorgen, K.A.K. Moldenhauer, A. Pereira. 2018. Screening diverse *japonica* rice genotypes for grain yield and quality under high nighttime temperature. *In*: R.J. Norman and K.A.K. Moldenhauer (eds.) B.R. Wells Arkansas Rice Research Studies 2017. Arkansas Agricultural Experiment Station Research Series 651:50-55.

Kumar, A., C. Gupta, J. Thomas, and A. Pereira. 2021. Genetic dissection of grain yield component traits under high nighttime temperature Stress in a rice diversity panel. Frontiers in plant science, 12, 712167. https://dx.doi.org/10.3389/fpls.2021.712167

Röth, S., P. Paul, and S. Fragkostefanakis. 2016. Plant heat stress response and thermotolerance. New Delhi: Springer. https://dx.doi.org/10.1007/978-81-322-2662-8_2

Pachauri, R. K., M.R. Allen, V.R. Barros, J. Broome, W. Cramer, R. Christ et al. 2014. Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Geneva: IPCC.

Peng, S., J. Huang, J.E. Sheehy, R.C. Laza, R.M. Visperas, X. Zhong, G.S. Centeno, G.S. Khush, and K.G. Cassman. 2004. Rice yields decline with higher night temperature from global warming. Proc. Natl. Acad. Sci. U.S.A. 101 (27):9971-9975.

Singh, S. D., B. Chakrabarti, and P.K. Aggarwal .2009. Impact of elevated temperature on growth and yield of some field crops, in Global Climate Change and Indian Agriculture, ed. P. K. Aggarwal (New Delhi: M/s Chandu Press), 45–47.

Xu J., A. Henry A., N. Sreenivasulu. 2020. Rice yield formation under high day and night temperatures-A prerequisite to ensure future food security. Plant Cell Environ. 43 1595–1608. https://dx.doi.org/10.1111/pce.13748

Ye C. R., M.A. Argayoso, E.D. Redoña , S.L. Sierra, M.A. Laza, C.J. Dilla, et al. 2012. Mapping QTL for heat tolerance at flowering stage in rice using SNP markers. Plant Breed. 131 33–41. https://dx.doi.org/10.1111/j.1439-0523.2011.01924.x

Zhao, L., J. Lei, Y. Huang, S. Zhu, H. Chen, R. Huang, Z. Peng, Q. Tu, X. Shen, and S. Yan. 2016. Mapping quantitative trait loci for heat tolerance at anthesis in rice using chromosomal segment substitution lines. Breeding Science 66(3):358-366. https://dx.doi.org/10.1270/jsbbs.15084

Zhu S., R. Huang, H.P. Wai, H. Xiong, X. Shen, H. He et al. 2017. Mapping quantitative trait loci for heat tolerance at the booting stage using chromosomal segment substitution lines in rice. Physiol. Mol. Biol. Plants 23:817–825.

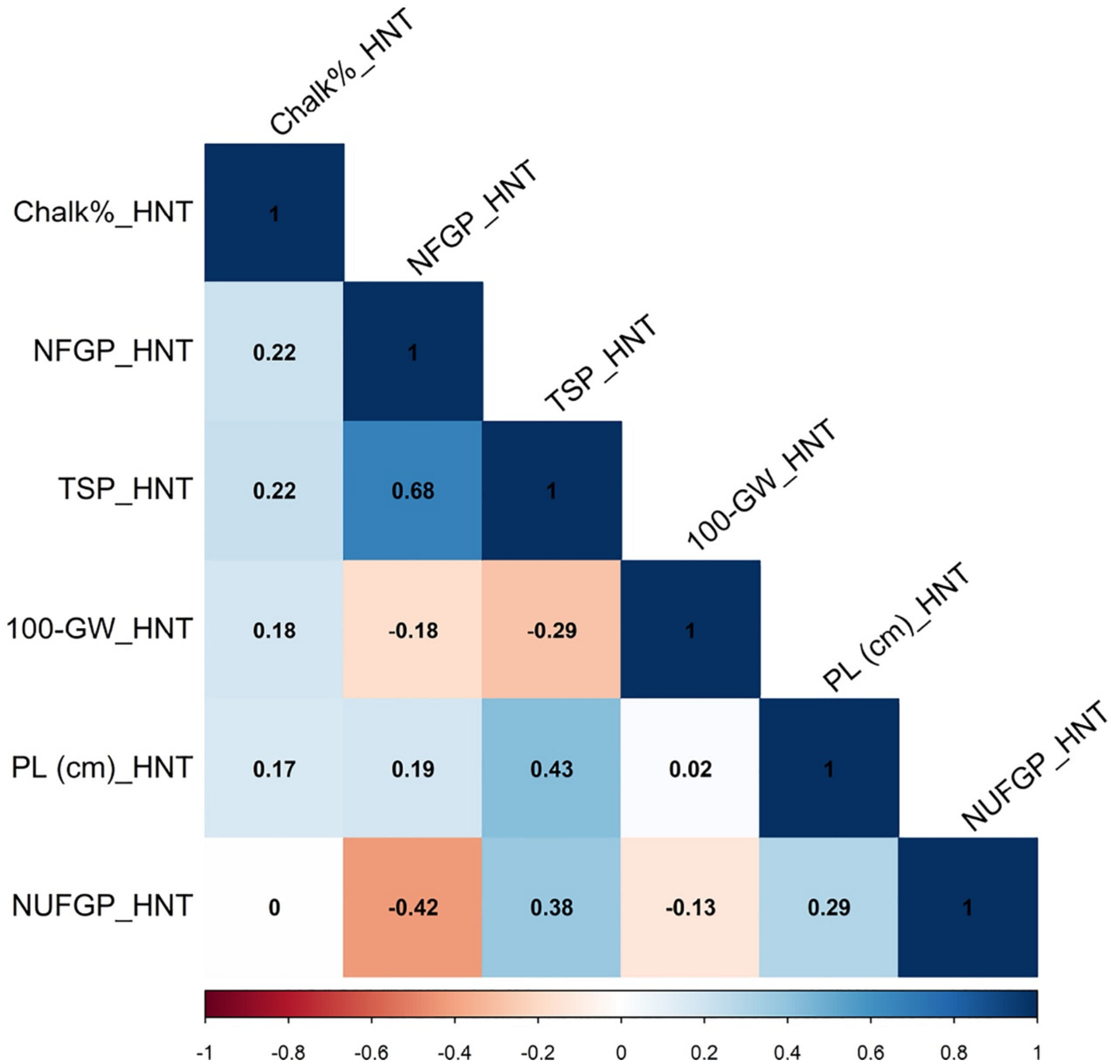

Fig. 1. Correlations between different grain yield and grain quality traits contributing to high nighttime temperature stress tolerance in a subpopulation of 81 diverse *Japonica* rice genotypes. The Pearson method was used to calculate the correlations between the traits for Panicle length (PL- cm), Total number of spikelets per panicle (TSP), Number of filled grains per panicle (NFGP), number of un-filled grains per panicle (NUFGP), 100- grain weight (100-GW), and Percent chalkiness (Chalk%).

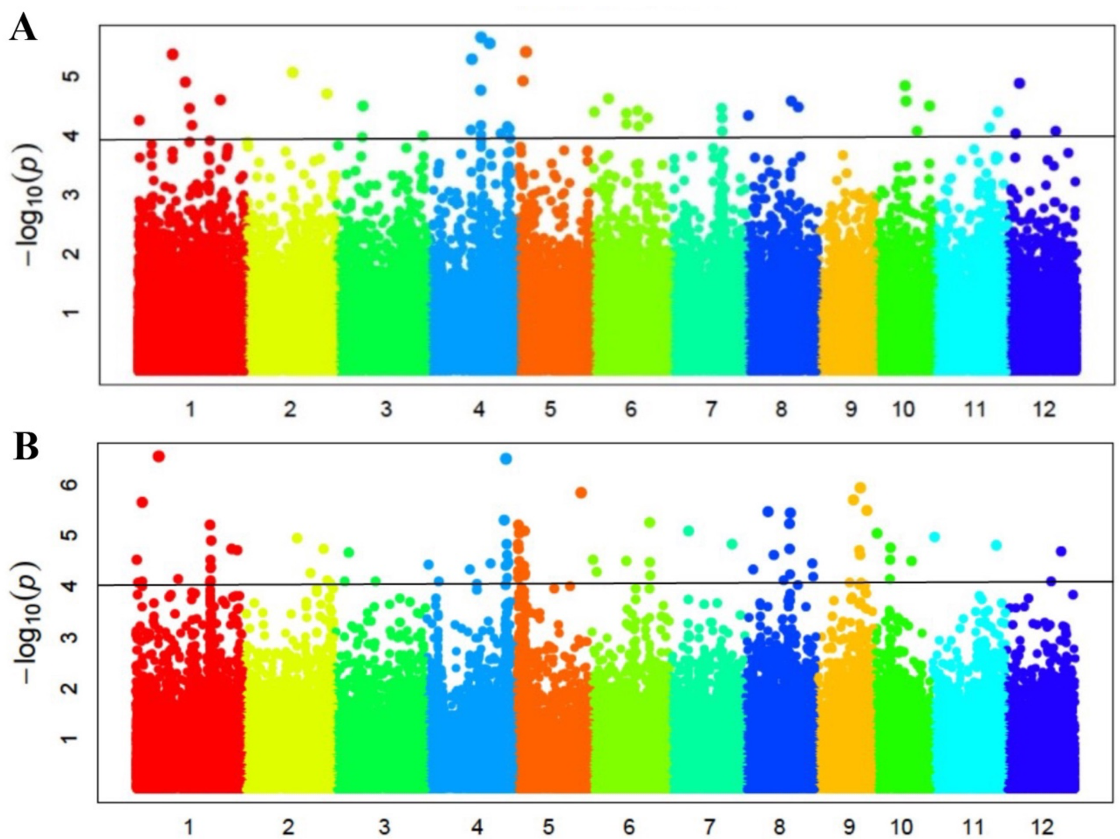

Fig. 2. Genome-wide association study (GWAS) of grain yield traits in a subpopulation of 81 *japonica* rice genotypes of the USDA Rice Mini-core Collection (URMC) under high nighttime temperature (HNT). The Manhattan plots show significantly associated single nucleotide polymorphisms (SNPs) (>-$\log_{10}$*p*-4.0) with total number of spikelets per panicle-TSP (A) and Number of un-filled grains per panicle-NUFGP (B). The horizontal black line in each plot represents the threshold that was set at -$\log_{10}$(4.0) and each colored dot in the plots represents single significantly associated SNPs showing significance above the thresholds set in the plots. These plots show stronger association of the traits with higher the - $\log_{10}$ (*P*-value) of the SNPs.

Table 1. Genome-wide significant single nucleotide polymorphisms (SNPs) associated with total number of spikelets per panicle (TSP) in the panel of 81 *Japonica* rice accessions under high nighttime temperature (HNT) stress.

S.No.	SNP	Chr[a]	Pos[b]	*P*-value	R^2	Pre Rep QTL[c]	QTL Region	Ref[d]
1	S1_860152	1	860152	5.49E-05	39.17			
2	S1_14079984	1	14079984	4.31E-06	54.45			
3	S1_19190092	1	19190092	1.23E-05	48.15			
4	S1_21792442	1	21792442	6.74E-05	43.70	qGN1.1	21.61-42.93	Cao et al., 2020
5	S1_33005790	1	33005790	2.53E-05	41.23			
6	S2_18549770	2	18549770	8.71E-06	46.87	qSFht2	11.33-35.43	Zhao et al., 2016
7	S2_31979684	2	31979684	2.01E-05	-28.88			
8	S3_10326363	3	10326363	3.15E-05	50.140			
9	S4_16755889	4	16755889	7.96E-05	45.34			
10	S4_17221730	4	17221730	5.086E-06	51.74	qSSP4	15.74-18.825	Buu et al., 2014
11	S4_20860056	4	20860056	2.25E-06	-27.36			
12	S4_20763826	4	20763826	6.80E-05	-22.38			
13	S4_20786024	4	20786024	1.70E-05	-22.05			
14	S4_24279531	4	24279531	2.77E-06	52.82			
15	S4_28719370	4	28719370	9.20E-05	38.67			
16	S4_31280415	4	31280415	7.10E-05	37.95			
17	S4_31967659	4	31967659	7.61E-05	34.91			
18	S5_2006019	5	2006019	1.21E-05	36.86			
19	S5_3102429	5	3102429	3.81E-06	41.08			
20	S6_6141945	6	6141945	2.40E-05	-23.38			
21	S6_13169066	6	13169066	4.13E-05	49.30			
22	S8_647433	8	647433	4.61E-05	45.65			
23	S8_20429062	8	20429062	3.41E-05	38.62	qDFT8	3.56- 28.24	Zhao et al., 2016
24	S10_11388157	10	11388157	1.46E-05	39.36			
25	S10_16125609	10	16125609	8.70E-05	40.00			
26	S10_21056829	10	21056829	3.19E-05	51.77	qDTF10.1	18.72-23.02	Zhao et al., 2016
27	S11_21799240	11	21799240	7.29E-05	-23.99	qDTF11	17.21-24.66	Zhao et., 2016
28	S11_25099842	11	25099842	4.07E-05	36.59			
29	S12_4535574	12	4535574	1.29E-05	30.41			
30	S12_18934798	12	18934798	8.52E-05	35.17			
31	S12_3075737	12	3075737	9.22E-05	39.96			

[a] Chromosome in the rice genome.
[b] Position of each SNP associated with traits in the genome.
[c] Previously reported quantitative trait loci (QTLs).
[d] Reference.

Table 2. Genome-wide significant single nucleotide polymorphisms (SNPs) associated with number of un-filled grains per panicle (NUNFGP) in the panel of 81 *Japonica* rice accessions under high nighttime temperature (HNT) stress.

S.No.	SNP	Chr[a]	Pos[b]	*P*-value	R^2	Pre Rep QTL[c]	QTL Region	Ref[d]
1	S1_9231726	1	9231726	2.6505E-07	33.91			
2	S1_2829400	1	2829400	2.13296E-06	32.16			
3	S1_40456445	1	40456445	1.91164E-05	31.55	qSF1	39.91-42.93	Cao et al., 2020
4	S2_20946249	2	20946249	1.10901E-05	30.85	qSFht2	11.34-35.43	Zhao et al., 2016
5	S2_26369378	2	26369378	5.4755E-05	32.3			
6	S3_5403966	3	5403966	2.15507E-05	45.09	qHTB3-2	12.33-22.40	Zhu et al., 2017
7	S3_16063117	3	16063117	8.16071E-05	37.4			
8	S4_17102703	4	17102703	4.63298E-05	29.6	qSSP4	15.74-18.83	Buu et al., 2014
9	S4_25326349	4	25326349	3.47172E-05	41.165			
10	S4_31376924	4	31376924	2.97697E-07	34.45			
11	S4_30768415	4	30768415	4.82119E-06	35.92			
12	S4_31278908	4	31278908	4.01122E-05	34.53			
13	S4_31280716	4	31280716	9.39496E-05	30.87			
14	S4_31642109	4	31642109	1.43102E-05	33.71			
15	S4_31860339	4	31860339	2.43428E-05	33.58			
16	S4_31878064	4	31878064	6.60235E-05	30.62			
17	S4_32357232	4	32357232	3.24236E-05	33.58			
18	S5_937132	5	937132	6.6516E-05	-19.11			
19	S5_1151397	5	1151397	8.99063E-06	39.853			
20	S5_25695702	5	25695702	1.42263E-06	42.21			
21	S5_3192704	5	3192704	7.90277E-06	34.73	qHTSF5.1	3.05-24.14	Ye et al., 2012
22	S6_2104651	6	2104651	5.19643E-05	32.52			
23	S6_23340159	6	23340159	6.03085E-05	34.79			
24	S8_9082425	8	9082425	3.32189E-06	61.84	qHTT8	3.56-28.24	Zhao et al., 2016
25	S8_11400888	8	11400888	2.3899E-05	33.15			
26	S8_21012411	8	21012411	9.45869E-05	32.77			
27	S9_14659226	9	14659226	1.9492E-06	39.19			
28	S9_17395652	9	17395652	1.14552E-06	-31.68			
29	S11_632624	11	632624	1.03831E-05	31.39			
30	S11_25193737	11	25193737	1.51576E-05	32.19			
31	S12_21873780	12	21873780	2.05995E-05	40.41			

[a] Chromosome in the rice genome.
[b] Position of each SNP associated with traits in the genome.
[c] Previously reported quantitative trait loci (QTLs).
[d] Reference.

CLL18, a new High Yielding, Short-Season, Long-Grain Clearfield® Rice Variety

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Abstract

The cultivar CLL18 is a new and very high-yielding, short-season, long-grain Clearfield® rice cultivar derived from the cross Roy J/CL142-AR. The CLL18 Breeder Head Row seed was released to BASF and Horizon Ag by the University of Arkansas System Division of Agriculture's Arkansas Agricultural Experiment Station to produce breeder and foundation seed in 2022 and 2023, respectively. The major advantages of CLL18 are its very high yield potential, high whole kernel rice milling yield, long kernel length, and low chalk. CLL18 is a non-semidwarf standard height long-grain rice cultivar with lodging resistance similar to Roy J. CLL18 is rated moderately susceptible to rice blast, sheath blight, and bacterial panicle blight, moderately resistant to narrow brown leaf spot, and susceptible to false smut.

Introduction

The cultivar CLL18 was developed in the rice improvement program at the University of Arkansas System Division of Agriculture's (UADA) Rice Research and Extension Center (RREC) near Stuttgart, Arkansas. Breeder Head Row seed was released to BASF, who released the line to Horizon Ag for seed production in 2022 and 2023. CLL18 has a very high rough rice grain yield and good milling yield. CLL18 is similar in maturity to CLL15 and similar in height to Diamond, with canopy heights of 37 and 36 in., respectively. CLL18 is rated moderately susceptible to common rice blast races and has a typical U.S. long-grain cook type. CLL18 was developed with the use of rice grower check-off funds distributed by the Arkansas Rice Research and Promotion Board.

Procedures

CLL18 rice (*Oryza sativa* L.) is a very high-yielding, short-season, long-grain Clearfield® rice cultivar developed by the Arkansas Agricultural Experiment Station. CLL18 originated from the cross Roy J/CL142-AR (cross no. 20113023), made at the RREC in 2011. The experimental designation for early evaluation of CLL18 was STG18IMI-01-121, starting with a bulk of F_8 seed from the 2018 panicle row IMI-01-121. CLL18 was tested in the Arkansas Rice Performance Trials (ARPT) and the Cooperative Uniform Regional Rice Nursery (URRN) during 2020–2021 as entry RU2001093 [RU number indicated URRN; 20 indicates year entered was 2020; 01 indicates Stuttgart, Arkansas; and 093 is entry number].

In 2020 and 2021, the ARPT was conducted at five locations in Arkansas: RREC; Northeast Research and Extension Center (NEREC), near Keiser, Ark.; Pine Tree Research Station (PTRS), near Colt, Ark.; Bowers Farm, Clay County (CLAY), near Corning, Ark.; and Whitaker Farm, Desha County (DESHA), near McGehee, Ark. The tests had four replications per location to reduce soil heterogeneity effects and to decrease the amount of experimental error. CLL18 was also grown in the URRN at RREC; Crowley, Louisiana; Stoneville, Mississippi; Beaumont, Texas; and Malden, Missouri from 2020 to 2021. The URRN test has three replications per location. Data collected from the ARPT and URRN tests included plant height, maturity, lodging, percent head rice, percent total rice, and grain yield adjusted to 12% moisture and disease reaction information. Cultural practices varied somewhat among locations, but overall the trials were grown under conditions of high productivity as recommended by the University of Arkansas System Division of Agriculture's Cooperative Extension Service Rice Production Handbook MP 192 (CES, 2021). Agronomic and milling data are presented in Tables 1 and 2. Disease ratings, which are indications of potential damage under conditions favorable for the development of specific diseases, have been reported on a scale from 0 = least susceptible to 9 = most susceptible, or as very susceptible (VS), susceptible (S), moderately susceptible (MS), moderately resistant (MR), and resistant (R), respectively. Straw strength is a relative estimate based on observations of lodging in field tests using the scale from 0 = very strong straw to 9 = very weak straw or totally lodged.

Results and Discussion

Rough rice yields of CLL18 compared favorably with Diamond in the 2020–2021 ARPT. In ten ARPT tests (2020 to 2021), CLL18, CLL15, CLL16, RT XP753, and Diamond averaged

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yields of 221, 207, 210, 247, and 206 bu./ac, respectively (Table 1). Data from the URRN conducted in Arkansas and Louisiana from 2020 to 2021 showed that the CLL18 average grain yield of 224 bu./ac compared favorably with those of CLL15, CLL16, and Diamond at 204, 219, and 204 bu./ac, respectively (Table 2). Milling yields (%whole kernel/%total milled rice) at 12% moisture from the 2020 ARPT averaged 59/69, 61/69, 59/69, and 60/70 for CLL18, CLL15, CLL16, and Diamond, respectively (Table 1).

CLL18 is a short-season variety maturing approximately two days later than CLL15. CLL18 has strong straw strength, which is an indicator of lodging resistance. On a relative straw strength scale based on field tests, CLL18 rated a 1.2 compared to CLL15, CLL16, and Diamond which rated 1.0, 1.0, and 1.0, respectively. CLL18 is a standard statured variety with an approximately 37-in. canopy height and 44-in. plant height, which is similar to Jewel and Diamond.

CLL18 is moderately susceptible to common rice blast races (*Pyricularia grisea* (Cooke) Sacc.), sheath blight (*Rhizoctonia solani* Kühn), bacterial panicle blight (*Burkholderia glumae* or other *Burkholderia* species) using the standard disease rating R = resistant, MR = moderately resistant, MS = moderately susceptible, S = susceptible, and VS = very susceptible to disease. CLL18 is rated S to false smut (*Ustilaginoidea virens* (Cooke) Takah) and MR to narrow brown leaf spot (*Cercospora oryzae*).

Plants of CLL18 have erect culms, green erect leaves, and glabrous lemma, palea, and leaf blades. The lemma and palea are straw-colored with straw-colored apiculi at maturity. Milled kernels of CLL18 have the desired long-grain size averaging 7.38 mm for the five locations of the 2020 ARPT compared to CLL15, CLL16, RT XP753, and Diamond, with grain sizes averaging 7.29, 7.37, 7.31, and 7.23 mm in kernel length, respectively. Individual milled kernel weights of CLL18, CLL15, CLL16, RT XP753, and Diamond averaged 21.8, 20.6, 22.7, 22.2, and 21.6 mg/kernel, respectively, from the ARPT 2020–2021 data from the Riceland Foods Inc. Quality Laboratory.

The endosperm of CLL18 is non-glutinous, nonaromatic, and covered by a light brown pericarp. Rice quality parameters indicate that CLL18 has typical southern U.S. long-grain rice cooking quality characteristics as described by Webb et al. 1985. CLL18 has an average apparent starch amylose content analysis of 23.4 g/kg, compared to CLL15, CLL16, RT XP753, and Diamond at 21.3 g/kg, 22.8 g/kg, 19.8 g/kg, and 22.3 g/kg, respectively and an intermediate gelatinization temperature of 69.5 °C compared to CLL15, CLL16, RT XP753, and Diamond, at 69.7 °C, 69.2 °C, 70.9 °C, and 69.6 °C, respectively, as measured by the Riceland Foods Inc. Quality Laboratory in 2020.

Practical Applications

The release of CLL18 provides producers with a very high-yielding, short-season, long-grain Clearfield® rice, which has typical Southern U.S. cooking quality.

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Literature Cited

Hardke, J. (ed.) 2021. Arkansas Rice Production Handbook. University of Arkansas System Division of Agriculture's Arkansas Cooperative Extension Service, MP 192, Little Rock, Ark.

Webb, B.D., C.N. Bollich, H.L. Carnahan, K.A. Kuenzel, and K.S. McKenzie. 1985. Utilization characteristics and qualities of United States rice. p. 25-35. In: Rice grain quality and marketing. IRRI, Manila, Philippines.

Table 1. Two-year average yield and agronomic data from the 2020–2021 University of Arkansas System Division of Agriculture's Arkansas Rice Performance Trials for CLL18 and other cultivars.

	Yield[a]				50%	Chalky	
Cultivar	2020	2021	Mean	Height[b]	Heading	Kernels[c]	Milling[d]
	----------------bu./ac----------------			(in.)	(days)	(%)	%HR/%TR
CLL18	217	224	221	37.7	87	3.44	59/69
CLL16	205	214	210	37.8	91	1.70	59/69
CLL15	200	213	207	33.0	86	2.57	61/69
RT XP753	239	254	247	37.4	85	2.99	60/72
Diamond	208	204	206	37.2	88	2.25	60/70

[a] Yield trials in 2020 and 2021 were conducted at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC), near Stuttgart, Ark.; Pine Tree Research Station (PTRS), near Colt, Ark.; Northeast Research and Extension Center (NEREC), near Keiser, Ark.; Bowers Farm, Clay County (CLAY), near Corning, Ark.; Whitaker Farm, Desha County (DESHA), near McGehee, Ark.

[b] Canopy height data collected from 2020 to 2021.

[c] Chalk data analysis from Riceland Foods Inc. Grain Quality Laboratory collected from 2020 to 2021.

[d] Milling figures are percent head rice/percent total milled rice collected in 2020.

Table 2. Two-year average yield and agronomic data from the 2020–2021 Uniform Regional Rice Nursery Arkansas and Louisiana locations for CLL18 and other cultivars.

	Yield[a]			Arkansas Yield[b]				50%	
Cultivar	2020	2021	Mean	2020	2021	Mean	Height[c]	Heading[d]	Milling[e]
	------------bu./ac-----------			-----------bu./ac-----------			(in.)	(days)	%HR/%TR
CLL18	216	233	224	231	260	246	46	92	58/69
CLL16	209	230	219	204	239	222	44	93	59/69
CLL15	196	212	204	165	228	197	40	89	61/69
Diamond	206	203	204	196	238	217	44	91	58/70

[a] Rice Research and Extension Center, Stuttgart, Ark.; Rice Research Station, Crowley, La.

[b] Arkansas URRN yields.

[c] Height data measured from ground to panicle tip in Arkansas 2020–2021 only.

[d] Heading data reported from Arkansas 2020–2021 only.

[e] Milling figures are percent head rice/percent total milled rice collected in 2020 only.

Hybrid Rice Breeding Progress and Revamp of the Program

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Abstract

Efforts have been made by the University of Arkansas System Division of Agriculture's Rice and Research Extension Center's (RREC) hybrid rice breeding program to develop hybrid rice (*Oryza sativa* L.) varieties that include 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 2022. 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 2022.

Introduction

A hybrid rice breeding program requires a multiple pipeline scheme compared to a more straightforward conventional rice breeding approach. This is due to the need for 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 self-pollinated 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 *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 the 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 a 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 for developing five parental lines (S, A, B, and R lines, and pollen parents). Essentially, it is almost like having five conventional rice breeding programs in one. 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 and further tested until a hybrid variety is identified.

Due to all of these complexities, the University of Arkansas System Division of Agriculture's Hybrid Rice Breeding Program at the Rice Research and Extension Center (RREC) near Stuttgart, Ark., has been revamped. The most notable shift of the program is to focus on the breeding of competitive hybrids through highly successful manual testcrossing and conducting a small plot (rows) observation trial (OBT) to streamline the breeding operation; to maximize the efficiency; and to leverage the elite breeding lines, winter nursery space, and yield trial capacity of other RREC breeding projects. This shift is in contrast to the previous impetuously scaled-up hybrid seed production of unproven experimental hybrids that resolved with little success. Breeding efforts include the introgression of desirable flowering traits into hybrid parental

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lines and emphasizing combining ability. The revamp was initiated during the planting season of 2021, so the program was limited in its efforts for change due to timing. The focus on breeding will be amplified in the 2022 season; however, at this time, the progress of 2021 will be discussed.

Procedures

2-Line Method

The 2-line method of hybrid rice production requires S line development, pollen parent selection, testcrossing, testcross evaluation, and hybrid seed production. The S line development consisted of 67 advanced lines derived from the RREC hybrid rice breeding program's thermo-sensitive genic male-sterile (TGMS) lines (North et al., 2019). These lines were evaluated based on combining ability and flowering characteristics used for testcrossing. Fifty-three of those lines were planted as panicle rows to evaluate their sterility and desirable phenotypes. Fourteen of those S-lines were used for testcrosses that were planted in two different ways: 1) 6-rows with 10-in. row spacing and 5 ft long, and row alteration consisting of males (M) and females (F) as M, F, F, F, M, M; 2) 8 rows with 8-in. row spacing and 10 ft long, and row alternating as: M, M, F, F, F, F, M, M. One hundred twenty-six testcrosses were attempted using method 1, and 1,000 testcrosses were attempted using method 2. Hybrid seed production of 10 experimental hybrids was attempted using a larger-scale method 2 in which planting length was 200 ft. Evaluation of selected testcrosses concluded with hybrid seed set amount.

Testcrosses were evaluated in two ways: 1) a preliminary yield trial that consisted of 87 testcrosses that were made in 2020 was planted in plots of 7 rows wide with 8-in. spacing and 15 ft length; 2) small plot OBT consisting of 194 testcrosses planted as rows with 10-in. row spacing and 5 ft length. Method 1 results concluded with combine-harvesting selected hybrid plots that displayed uniformity, and method 2 concluded with an evaluation of hybrid rows based on plant uniformity, desirable phenotypes, maturity, hand-harvest of best-looking testcrosses, milling, and quality evaluation.

S lines development with Provisia® technology was started in 2019. In 2021, 763 F_3 lines were space-planted and selected based on sterility, desirable phenotypes, and Provisia® herbicide tolerance. Plots were 4 rows wide with a 16-in. spacing and 15 ft in length. Selected plants were later dug up, placed into pots, and placed inside a greenhouse for seed production in late fall.

3-Line Method

The 3-line method of hybrid rice production requires A, B, and R line development; testcrossing; testcross evaluation; and hybrid seed production. The hybrid rice breeding program started A and B line development previously with lines accessible through the USDA world collection. In 2021, some testcrosses were made between A and R lines for hybrid seed production and evaluation of A and R lines. However, testcrossing will continue in the greenhouse in spring 2022.

Four hundred thirty-two F_3 B lines were planted as panicle rows and selected based on desirable phenotypes. One thousand two hundred thirty-one B lines spanning from F_4 to F_6 were also planted and evaluated as panicles rows. Testcrosses were made with A lines, and the progeny must be evaluated in the 2022 season to determine complete sterility for the development of new A lines.

Currently, there are 55 advanced R lines developed. Fifteen of those lines were used to make testcrosses with A and S lines. The progeny of the testcrosses must be evaluated to determine the restorer ability of the R lines in the 2022 season and to observe the hybrid phenotypes. Forty of the advanced R lines were planted in the Stuttgart Initial Test (SIT). There were 1,560 F_3 lines planted as panicles rows and selected based on desirable phenotypes. Seven hundred sixty-four R lines spanning from F_4 to F_6 were also planted and evaluated as panicle rows.

A total of 105 3-line testcrosses made in 2020 were evaluated as individual rows for maturity, height, uniformity, row weight, milling, and grain appearance.

Results and Discussion

2-Line Method

A total of 279 testcrosses and 13 experimental hybrids were produced in 2021. The 4 most promising hybrids will be tested in the 2022 Arkansas Rice Variety Advancement Trials (ARVAT), 10 will be tested in the Advanced Elite Line Yield Trial (AYT), 3 will be tested in the first-ever Clearfield® (CL) hybrids in the CL AYT (CAYT), and 33 will be tested in the SIT. One hundred ninety conventional long-grain testcrosses will be tested in the OBT as individual rows, and 69 CL testcrosses will be tested as individual rows in CL OBT to evaluate for desirable phenotypes, maturity, seed setting, yield potential, milling, and grain and cooking quality.

All 2020 testcrosses that were tested in the preliminary yield trial showed poor heterosis. It was noticed that many of the plots were not uniform due to the segregation of the female S lines. The S lines will need to be further selected to achieve uniformity, purity, and stability before using for testcrossing. The purification and increase are underway and will continue throughout 2022. Most of the 194 testcrosses evaluated in OBT as individual rows in 2021 appeared uniform with desirable phenotypes. These testcrosses will be re-produced with more seed in 2022 and introduced into various yield trials, including ARVAT in 2023.

Fifty-four individual plants were selected from the Provisia® S line space plants. These plants were removed from the field and placed inside a greenhouse in the late fall to induce seed production. As a result, 43 plants produced seeds. The F_4 seed collected will be tested again as space plants in 2022.

3-Line Method

Fifty-eight testcrosses were produced in 2021. One will be in the advanced yield trial and 57 in OBT as individual rows to evaluate for plant uniformity and desirable phenotypes. More 3-line crosses will be attempted in 2022.

A and B line development will be continued in 2022. Additional backcrosses and testcrosses are planned for A line development.

Of the 40 advanced R lines tested in the 2021 preliminary yield trial, 3 performed well (200 bu./ac) as compared with Diamond, Lakast, and RoyJ, which yielded around 208 bu./ac.

Approximately half of the earlier generation (F_3–F_4) R lines were selected to be advanced in 2022. One hundred of the R lines were used for testcrossing to evaluate their restoring and combining ability in 2022. More testcrosses are planned for 2022 to increase the number of advanced R lines to use for developing hybrids to be tested in 2023.

Practical Applications

Four S lines have been selected as the prominent females to be crossed with many pollen parents in 2022 for 2-line hybrid seed production. Efforts are being made to develop S lines with Provisia® technology that will later be used for the development of Provisia® hybrid varieties. Three A lines have been selected as prominent females for 3-line hybrid seed production. 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. Sufficient amounts of hybrid seeds were produced in 2021, which enables us to have 13 new hybrids (including 3 first-ever CL hybrids) to be evaluated in the 2022 AYT, while 4 of those will simultaneously be tested in the 2022 ARVAT. As mentioned previously, the revamped program will continue to shift focus into breeding for new and improved parental lines, including S and A lines, in 2022 to accelerate the progress in developing hybrid rice varieties with commercial-scale performance.

Acknowledgments

We would like to express our appreciation for funding and support from the Arkansas rice growers administered through the Rice Research and Promotion Board and the University of Arkansas System Division of Agriculture. We thank Emily Carr and Richard Weaver for their technical support.

Literature Cited

North, D. G., E. Shakiba, S. Fei, P. Counce, and K. Moldenhauer. 2019. Characterization and application of Arkansas male sterile lines for hybrid rice production. https://dr.lib.iastate.edu/entities/publication/30840c17-82ce-4c3d-89ef-9993cdfa40da

Li, S., D. Yang, and Y. Zhu, 2007. Characterization and use of male sterility in hybrid rice breeding. J. Integrative Plant Biol. 19 (6):791-804.

Virmani, S.S., X.Z. Sun, T.M. Mou, Jauhar A.A, and C.X. Mao. 2003. Two-line hybrid rice breeding manual. International Rice Research Institute, Los Baños, Philippines. Page 1-4, 37. http://irri.org/resources/publications/books/item/two-line-hybrid-rice-breeding-manual

Virmani, S.S., B.C. Viaktamath, C.L. Casal, R.S. Toledo, M.T. Lopez, and J.O. Manalo. 1997. Hybrid rice breeding manual. International Rice Research Institute, Los Baños, Philippines. Page 9-20. http://books.irri.org/9712201031_content.pdf

Late, Fertile Panicle Response of Arkansas Temperature Sensitive Male Sterile Rice Lines to Seeding Rate for Hybrid Seed Production

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Abstract

Two-line hybrid rice (*Oryza sativa* L.) production requires an environment-sensitive genetic male-sterile (EGMS) line in which sterility is induced by high temperatures (TGMS), long photoperiod (PGMS), or both (PTGMS). Later in the rice-growing season, temperatures will lower, and TGMS lines can produce late tillers, which could form fertile panicles (self-pollination). This would reduce hybrid seed purity. The seeding rate of the EGMS line could minimize this issue because the higher the seed rate, the higher the plant density, which would reduce the number of late tillers. Two Arkansas TGMS lines, 801s and 811s, were tested with four different seeding rates (20, 30, 40, and 60 lb/ac). Plots were planted in a randomized block design with three replications at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC) near Stuttgart, Ark. Tillers were counted from the three centermost rows of each 7-row plot to avoid border effects. The number of tillers was categorized as late tillers (no panicles exerted) and mature tillers (panicles exerted). The results showed that there is no significant difference in the number of late tillers among the seeding rates; thus, seeding rate does not significantly reduce late tillers for hybrid seed purification. There was a significant difference in the number of mature tillers between the 20 and 60 lb/ac rates. An optimum seed rate of 30 lb/ac is recommended for an ample number of panicles for hybrid seed production because there is no significant gain of mature tillers using the higher seeding rates. This could help reduce hybrid seed costs by avoiding over-seeding the EGMS lines while maximizing hybrid seed production yields.

Introduction

Yield and seed purity of 2-line hybrid rice depend greatly on the EGMS line, which acts as the female parent, bearing the hybrid seed after successful pollination. Foremost, the EGMS line must be sterile in which pollen sterility of the plants should be >99.5% (Virmani et al., 2003). For temperature-sensitive EMGS lines (TGMS), high daily temperatures must exceed a certain threshold (for most lines when day temperatures are >86 °F) (Virmani et al., 2003) to induce complete sterility during a short window during the plant's reproductive stage (R1 + 10 days) (North et al., 2019). This can be risky for hybrid seed production in locations where temperatures may not reach the threshold or locations prone to temperature fluctuations (caused by storms, higher elevation, etc.). Even if temperatures are above the threshold during the short reproductive stage window, rice can develop late tillers when temperatures are lower than the threshold later in the growing season, which would produce fertile panicles. The fertile panicles would self-pollinate and compromise hybrid seed purity.

In a previous study by North et al. (2019), it was determined that TGMS lines developed by Yan et al. (2010) at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC) in Stuttgart, Arkansas, are sterile during Arkansas' rice-growing season (optimum planting date of 25 April). Possibilities of late tillers producing fertile panicles can still be a concern in Arkansas because temperatures can fluctuate due to untimely cold fronts or hurricanes formed in the Gulf of Mexico. Another concern would be the delay of planting or harvest due to wet field conditions or other management issues (equipment breakdown), which would place late tiller development further into the season as temperatures drop.

North et al. (2019) looked at different seeding rates to reduce late tiller formation for hybrid seed purity. The idea was that higher plant densities determined by seeding rates would reduce late fertile tillers. Arkansas TGMS line 811s was planted on 20 July 2018. A late planting date was selected to increase the chance of having conditions to produce late tillers with fertile panicles. Three seeding rates were chosen: 20, 40, and 80 lb/ac. It was discovered, however, that seeding rates did not significantly affect the number of late tillers with fertile panicles. Seeding rates do significantly affect the number of tillers with sterile panicles, which should be tested to maximize hybrid seed production yields while avoiding over-seeding of the TGMS line (affecting the cost of hybrid seed). Based on these results, it was decided that another seeding rate test should be attempted in order to further verify that seeding rates do not affect late tiller development that could form fertile panicles.

Procedures

Building upon the initial seed rate study in 2018, four seeding rates (20, 30, 40, and 60 lb/ac) were selected as treatments for two RREC TGMS lines (801s and 811s). The test was planted at RREC near Stuttgart, Ark., on 13 July. Plots were 7 rows with 8-in. spacing (5 ft wide) and 7 ft long tested in a randomized block design

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with three replications. The three centermost rows of each plot were cut to avoid border effects. Tillers of each row were counted and categorized as mature tillers (panicles exerted) and late tillers (no panicles exerted). The mature and late tillers counted from the three rows of each plot were averaged altogether to represent the whole plot; thus, 72 rows were evaluated to represent 24 plots.

Results and Discussion

Initially, mature tillers were to be further categorized according to whether panicles were sterile or fertile; however, Arkansas experienced average temperatures in 2021, which led to daily temperatures being near or below the sterility threshold of both RREC TGMS lines (85 °F) during the critical reproductive stages causing complete self-pollination of almost all the plants (Figs. 1 and 2). The dates in the figures are a week apart because 811s mature earlier than 801s. Heading dates are important to note for the EGMS lines because a one-week difference could result in greater pollen sterility/fertility variation if there is a drastic change in temperatures due to seasonal change or severe weather events.

There was no significant difference in the seeding rates for tillers with no panicles produced (late tillers) (Table 1). These tillers without panicles could produce panicles, given more time for plant growth. Without significant differences, seeding rates most likely do not affect late or non-panicle-producing tillers. The original hypothesis that late tillers producing fertile, self-pollinating panicles could be controlled by seeding rates is most likely false based on the results from both years of the seed rate study.

For the tillers with panicles, there was only a significant difference between the high (60 lb/ac) and the low (20 lb/ac) seeding rates (Table 1). Although statistically not significant, numeric differences were observed in the number of late tillers among different seeding rates (Table 1). Based on these results, it is recommended that a seeding rate of 30 lb/ac should be used because there is no significant gain in using the higher seeding rate for panicle production. Over-seeding EGMS lines is costly to hybrid seed production because of the cost and efforts in producing EGMS seed, and it could also affect purity because of the difficulty of rouging through thicker plant stands.

Practical Applications

There are now two years of data to verify that seeding rates do not significantly affect late tiller development; however, it does significantly affect the number of panicles produced. An optimum seeding of 30 lb/ac for 801s and 811s is recommended for an ample number of panicles while avoiding over-seeding. The seeding rates of TGMS lines for hybrid seed production may not significantly affect hybrid seed purity; however, based on these findings, TGMS seeding rates should be further evaluated to determine a recommended rate for maximized hybrid seed production yields without over-seeding to help reduce costs.

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Literature Cited

North, D.G., E. Shakiba, S. Fei, P. Counce, and K.A.K. Moldenhauer, 2019. Characterization and application of Arkansas male sterile lines for hybrid rice production. https://dr.lib.iastate.edu/entities/publication/30840c17-82ce-4c3d-89ef-9993cdfa40da

Virmani, S.S., X.Z. Sun, T.M. Mou, Jauhar A.A, and C.X. Mao. 2003. Two-line hybrid rice breeding manual. International Rice Research Institute, Los Baños, Philippines. Page 1-4. http://irri.org/resources/publications/books/item/two-line-hybrid-rice-breeding-manual

Yan, Z, W. Yan, and C. Deren. 2010. Hybrid rice breeding. *In*: R.J. Norman and K.A.K. Moldenhauer (eds.) B.R. Wells Rice Research Studies: Arkansas Agricultural Experiment Station Research Series 591:61-63. Fayetteville.

Table 1. Effects of seeding rate on number of tillers per 7-ft row averaged of temperature-sensitive genetic male-sterile (TGMS) lines 801s and 811s, at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center, Stuttgart, Ark., 2018 and 2021.

Seeding rate	Number of late tillers	Number of mature tillers
(lb seed/ac)		
20	35.2 a†	143.2 b
30	38.8 a	167.2 ab
40	38.9 a	161.7 ab
60	43.2 a	196.4 a
$LSD_{0.05}$‡	15.3	37.8

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

‡ LSD = least significant difference.

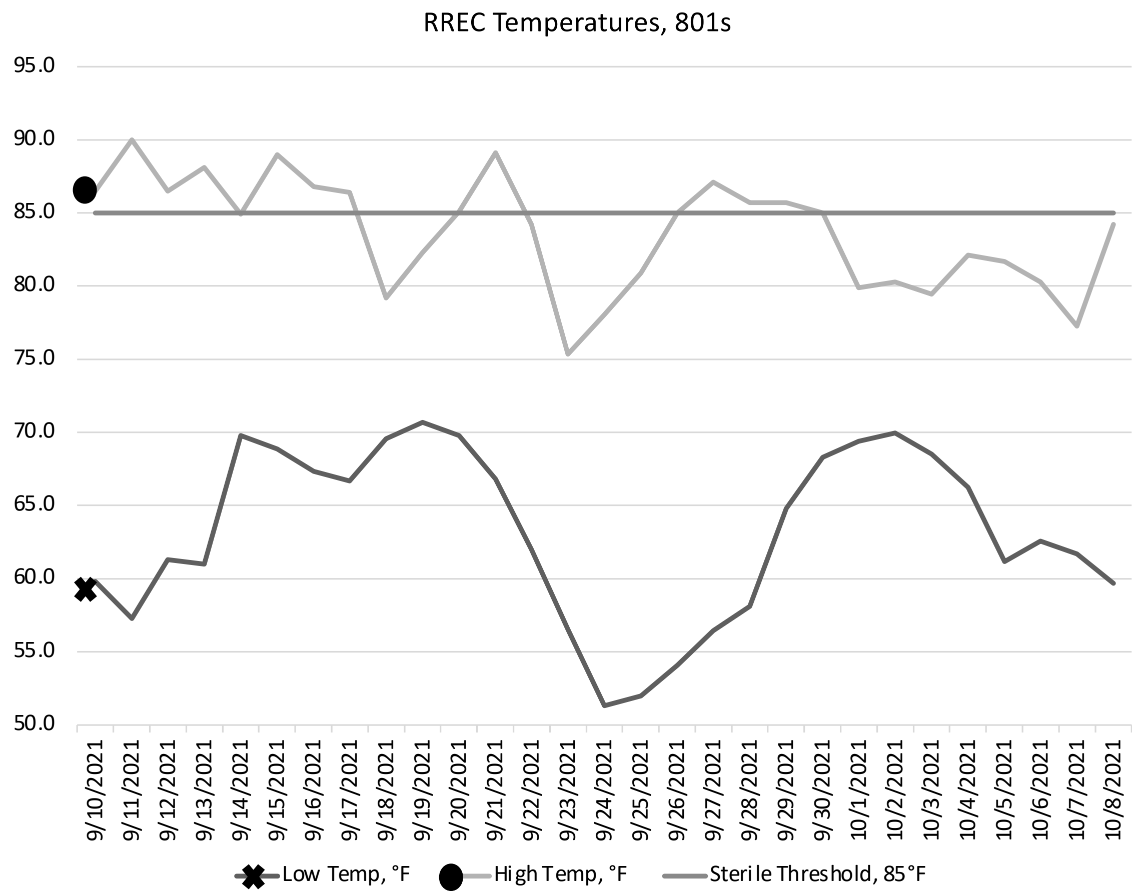

Fig. 1. High and low temperatures (°F) recorded at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center, Stuttgart, Ark., of dates for reproductive stage 1 (R1) through heading stage of 801s.

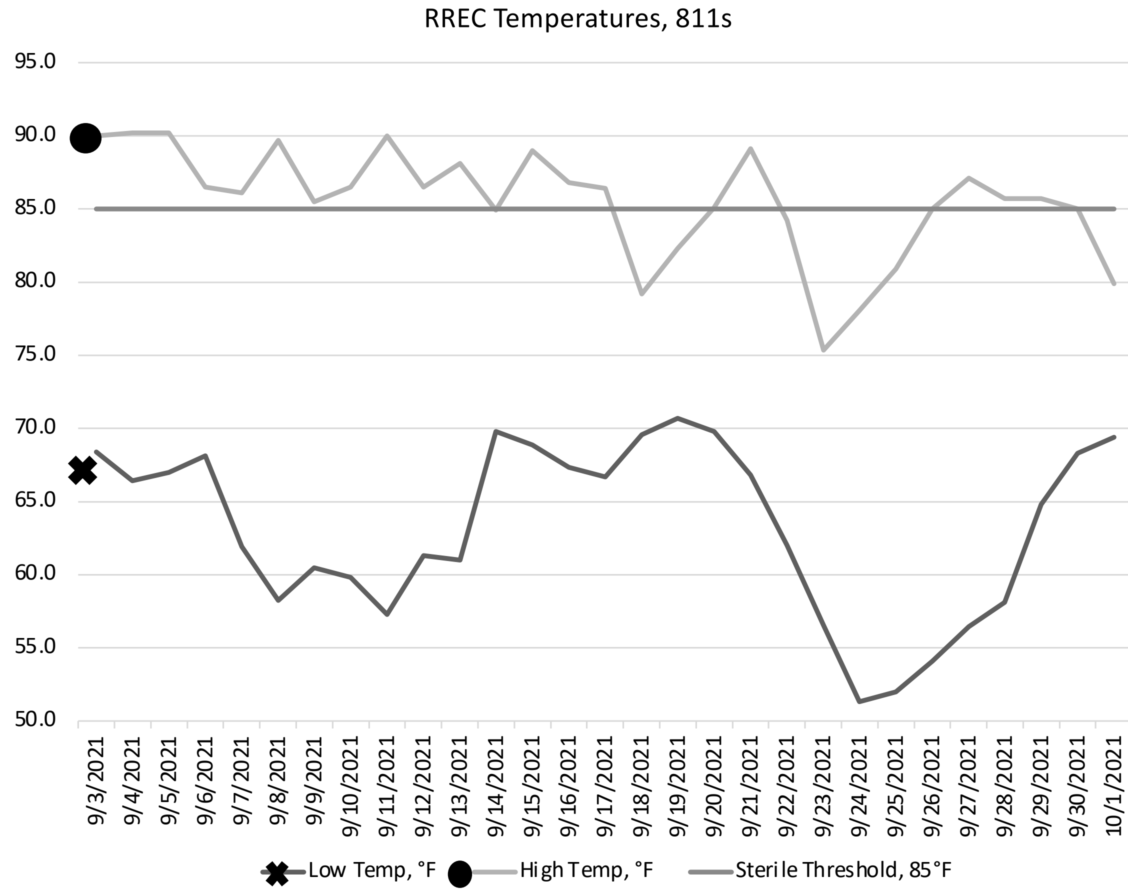

Fig. 2. High and low temperatures (°F) recorded at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center, Stuttgart, Ark., of dates for reproductive stage 1 (R1) through heading stage of 811s.

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 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, and an advanced elite line yield trial (AYT) were 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 Pine Tree Research Station (PTRS), near Colt, Ark.; and the 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 rice 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 a 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 1,200 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 include the multi-state Uniform Regional Rice Nursery (URRN) and statewide Arkansas Rice Variety Advancement Trials (ARVAT) that only accommodate about 25 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 the 2021 AYT trial at 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.; and the Northeast Research and Extension Center (NEREC), in Keiser, Ark, which included 69 experimental inbred lines (14 CL long-grain, 9 CL medium-grain, 2 PV long-grain, 33 conventional long-grain, and 11 conventional medium-grain), and 11 commercial check varieties. Twenty-eight of the experimental lines were also concurrently tested in the 2021 URRN and/or ARVAT trials. As companion tests, a 40-entry CL AYT (CAYT) and a 50-entry PV AYT (PAYT) were also carried out, and a 2X recommended rate of NewPath and Provisia herbicides were applied, respectively. The CAYT included 35 experimental CL lines (23 CL long-grain, 11 CL medium-grain, and 1 CL Jasmine-type line) and 5 commercial checks, while the PAYT consisted of 47 PV long-grain lines and 3 commercial checks. The experimental design is a randomized complete block with three replications. Plots measuring 4.38 feet wide (7 rows with 7.5-in. row spacing) and 14.25 feet long were drill-seeded at a 95 lc/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 19 April, PTRS on 13 April, and 7 May (PAYT), and RREC on 5 April (CAYT RB1), 12 April (AYT), 7 May (PAYT), and 13 May (CAYT RB2). A single pre-flood application of 135 lb (160 lb for 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 Classic or Wintersteiger Quantum plot combine (Wintersteiger AG, 4910 Ried, Austria), and the moisture

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content and plot weight were determined by the automated weighing system Harvest Master that is integrated into the combines. A small sample of seed was collected off 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 bushels per acre at 12% moisture content.

Data were analyzed using the General Linear Model procedure of SAS software, version 9.4 (SAS Institute, Cary, N.C.). A combined 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 test at the 0.05 probability level.

Results and Discussion

The average AYT grain yield of all entries across 3 locations is 232 bu./ac (Table 1), which is higher than the 220 and 195 bu./ac average in 2020 and 2019, respectively. The PTRS has the highest average yield of 247 bu./ac and followed by 233 and 215 bu./ac of RREC and NEREC, respectively. The average grain yield of medium-grain entries is 237 bu./ac, which is 7 bu./ac higher than long-grain entries. The top 5 highest yielding entries are commercial hybrids XL753 and RT7521 FP, followed by experimental CL medium-grain experimental line 21AYT17, the newly released conventional medium-grain variety Taurus, and CL medium-grain lines 21AYT23 with the average grain yield of 299, 293, 265, 256, and 255 bu./ac, respectively. The average milled head rice and total rice across locations are 60% and 67%, respectively, which are lower than the 66% and 71% in 2020, and 62% and 71% in 2019.

The five highest-yielding conventional medium-grain entries are Taurus, Lynx, 21AYT79 (RU1901165), 21AYT61 (RU2101218), and 21AYT60 (RU2101113) with the average yield of 256, 249, 244, 242, and 240 bu./ac, respectively. Meanwhile, six of nine CL medium-grain lines out-yielded both Jupiter and CLM04, which include 21AYT17, 21AYT23, 21AYT27 (RU2101234), and 21AYT45 (RU1801238), with an average yield of 265, 255, 247, 247, and 243 bu./ac, respectively. Three CL long-grain experimental lines outperformed both CLL15 and CLL16, which include 21AYT29 (RU2101101), 21AYT18 (RU1801101), and 21AYT21, with an average grain yield of 247, 240, and 234, respectively. Of 35 conventional experimental long-grain lines, 15 out-yielded Diamond and all but 1 outperformed Jewel. Among the top-performing lines, 21AYT36, 21AYT57, 21AYT33, 21AYT65 (RU2001125), and 21AYT77 (newly released Ozark) have an average yield of 254, 252, 250, 250, and 249 bu./ac, respectively, as compared with 232 bu./ac of Diamond and 205 bu./ac of Jewel. Most of these top-yielding experimental lines will be advanced or re-tested in the 2022 ARVAT and/or URRN trials.

The average grain yield of CAYT across locations/planting dates is 214 bu./ac (Table 2). The PTRS site has the highest grain yield of 236 bu./ac, followed by 215 bu./ac of RREC planted on 5 April and 191 bu./ac of RREC planted on 13 May. The average milling yields are 59% head rice and 66% total rice. Among 23 CL long-grain entries, 2 outperformed CLL16, 9 out-yielded CLL15, and 16 outperformed CLL17. The top 5 lines are 21CAYT40 (21AYT14), 21CAYT07 (21AYT29 and RU2101101), 21CAYT06 (21AYT12), 21CAYT17, and 21CAYT18 (21AYT18 and RU1801101) with an average yield of 236, 236, 229, 226, and 226 bu./ac, respectively. The CL medium-grain lines that performed well in the AYT trial also have an outstanding grain yield when treated with a 2X recommended rate of NewPath herbicide. The top-performing lines include 21CAYT19 (21AYT17), 21CAYT13 (21AYT27 and RU2101234), 21CAYT25 (21AYT45 and RU1801238), 21CAYT26 (21AYT23), and 21CAYT11 (21AYT22). The sole CL jasmine-type long-grain line 21CAYT12 (RU2101208) yielded significantly higher than commercial check CLJ01 with an average yield of 209 bu./ac as compared with 180 bu./ac of CLJ01.

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 period of time and tested in our inaugural advanced PV trials (Table 3). The average grain yield is 183 bu./ac, and the average milling yields are 55% head rice and 65% total rice. Of the 47 experimental lines, 6 outperformed commercial check PVL03 and 18 out-yielded PVL02. The top-performing lines are 21PSIT2035, 21PSIT2023, 21PSIT2016, 21PSIT2033, and 21PSIT2004, with an average grain yield of 212, 211, 205, 205, and 203 bu./ac, respectively.

Practical Applications

The 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 very limited number of entries by offering opportunities for the trial of additional elite breeding lines. Our results enable us to confirm the findings from other yield trials and to identify the outstanding breeding lines, which otherwise were excluded from URRN or ARVAT trials due to insufficient space.

Acknowledgments

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Table 1. Grain and milling yields of 80 long-grain 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 (NEREC) at Keiser, Ark., Pine Tree Research Station (PTRS) near Colt, Ark., and Rice Research and Extension Center (RREC) near Stuttgart, Ark., 2021.

Entry	Pedigree	Grain Type†	Grain Yield NEREC	PTRS	RREC	Mean	%HR/%TR‡
			--------------(bu./ac)--------------				
21AYT01	Diamond	L	210	242	244	232	55/66
21AYT02	Jewel	L	189	211	216	205	57/67
21AYT03	CLL15	CL	222	235	231	229	59/67
21AYT04	CLL16	CL	214	245	238	232	57/66
21AYT05	CLL17	CL	187	253	222	221	61/67
21AYT06	CLM04	CM	214	230	234	226	64/67
21AYT07	Jupiter	M	203	273	218	231	64/66
21AYT08	Lynx	M	235	271	242	249	63/67
21AYT09	XP753	L	306	267	326	299	57/68
21AYT10	RT7521FP	FPL	290	269	321	293	59/67
21AYT11	PVL03	PVL	206	216	216	213	60/68
21AYT12	RU1102034/CL172	CL	231	234	213	226	59/67
21AYT13	RU1202137/RU1501024	CL	230	249	182	220	61/67
21AYT14	DMND/RU1701096	CL	216	230	233	226	60/68
21AYT15	MRMT/RU1501185	CL	186	242	200	209	60/67
21AYT16	RU1102034/RU1501024	CL	222	252	216	230	60/67
21AYT17	RU1501050/RU1501027	CM	261	264	269	265	62/67
21AYT18	CL172/RU1102034	CL	242	250	228	240	62/68
21AYT19	ROYJ*2/14CSIT203	CL	217	239	237	231	60/68
21AYT20	RU1301030/14CSIT314	CM	211	219	231	220	63/68
21AYT21	ROYJ/CL111	CL	225	248	228	234	60/67
21AYT22	RICO/BNGL//RU1202068	CM	237	253	240	243	61/66
21AYT23	16ARPT271/RU1601050	CM	235	276	254	255	63/67
21AYT24	16AYT054/15CSIT771	CM	163	242	197	201	62/67
21AYT25	JPTR/TITN//15CSIT769	CM	228	256	241	242	62/66
21AYT26	RU1601124/RU1601096	CL	156	229	182	189	60/69
21AYT27	14SIT818/RU1501096	CM	223	268	250	247	61/65
21AYT28	RU1401136/CL172	CL	172	221	186	193	60/69
21AYT29	RU1302048/CL151	CL	237	273	231	247	60/67
21AYT30	RU1102034/RU1501024*2	CL	227	237	226	230	63/68
21AYT31	TGRT/RU1102134	L	221	236	228	228	62/69
21AYT32	RU0502137/07SP291	M	191	270	223	228	60/67
21AYT33	DMND/LKST	L	224	273	254	250	60/68
21AYT34	DMND/LKST	L	210	257	250	239	53/60
21AYT35	DMND/LKST	L	218	249	227	231	56/67
21AYT36	DMND/LKST	L	235	270	255	254	62/69
21AYT37	DMND/RU1201136	L	220	226	244	230	60/69
21AYT38	RU1102131/14CSIT203	CL	208	255	208	223	63/69
21AYT39	RU1201127/DMND	L	212	258	239	236	58/68
21AYT40	ROYJ/RU1501127	L	224	257	241	241	56/67

Continued

Table 1. Continued.

Entry	Pedigree	Grain Type[†]	Grain Yield NEREC	PTRS	RREC	Mean	%HR/%TR[‡]
			--------------(bu./ac)--------------				
21AYT41	14SIT818/14SIT873	M	201	253	227	227	62/65
21AYT42	JPTR/EARL	M	193	251	211	218	63/66
21AYT43	CL271/JPTR	CM	234	256	238	243	64/68
21AYT44	FRNS/TGRT	L	201	237	231	223	59/69
21AYT45	EARL/9902028//RU1202068	CM	216	266	258	247	63/68
21AYT46	FRNS/TGRT	L	214	239	214	222	60/68
21AYT47	FRNS/TGRT	L	208	233	223	221	60/68
21AYT48	DMND/TGRT	L	217	265	244	242	59/67
21AYT49	ROYJ/RU1201136	L	181	219	232	211	59/68
21AYT50	FRNS/DMND	L	219	224	239	227	60/68
21AYT51	MRMT/LKST	L	209	223	211	214	58/67
21AYT52	TITN/07SP301	M	209	237	222	223	62/65
21AYT53	18AYT62/1201145//HPHI2/	PVL	222	240	198	220	51/65
21AYT54	RU1201127/RU1401099	L	162	218	216	198	57/68
21AYT55	(RU1102131/…)*2/HPHI2	PVL	135	171	147	151	56/66
21AYT56	RU0902125/RU1102034	L	227	244	210	227	61/68
21AYT57	RU1201111/DMND	L	227	272	255	252	61/68
21AYT58	17AYT06/RU1601070	L	222	251	242	238	59/68
21AYT59	ROYJ//ROYJ/RU0902140	L	222	228	245	231	60/68
21AYT60	RICO/BNGL//RU0502137	M	218	251	249	240	60/65
21AYT61	RICO/BNGL//CFFY	M	232	266	229	242	64/67
21AYT62	RU1701084/RU1601070	L	209	245	240	231	58/68
21AYT63	JPTR//EARL/9902028	M	213	271	228	237	63/66
21AYT64	DMND/JEWL	L	210	256	248	238	56/68
21AYT65	ROYJ/RU1501127	L	240	255	255	250	59/68
21AYT66	JEWL/RU1601070	L	222	257	236	238	57/67
21AYT67	CFFY/14SIT891	M	213	248	231	231	63/67
21AYT68	RU1601070/JEWL	L	210	247	248	235	57/68
21AYT69	RU1601070/JEWL	L	205	238	238	227	57/67
21AYT70	JPTR/J062	M	205	261	229	232	65/67
21AYT71	RU1801173/RU1601070	L	207	237	255	233	60/69
21AYT72	RU1401142/RU1201111	L	218	247	254	240	58/69
21AYT73	RU1401142/RU1201111	L	207	246	233	229	62/70
21AYT74	RU1701084/RU1601145	L	214	228	241	228	61/69
21AYT75	RU1701084/RU1601145	L	201	248	229	226	57/68
21AYT76	RICO/BNGL//0602162/…	M	241	274	254	256	64/69
21AYT77	DMND/LKST	L	233	256	256	249	59/68
21AYT78	DMND/RU1601130	CL	206	251	235	231	58/69
21AYT79	RU1001067/RU0602171	M	234	269	231	244	65/67
21AYT80	ROYJ/RU1501127	L	226	226	237	230	58/68
c.v.(%)[§]			n/a	9.6	3.6	7.8	3.9/1.6
$LSD_{0.05}$			n/a	38.2	13.5	21.1	2.2/1.0

[†] Grain type, CL = Clearfield® long-grain, CM = Clearfield® medium-grain, PVL = Provisia® long-grain, FPL = FullPage®, L = conventional long-grain, and M = conventional medium-grain.

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

[§] Coefficient of variance.

Table 2. Grain and milling yields of 40 Clearfield® (CL) long-grain 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 (PTRS) near Colt, Ark., and Rice Research and Extension Center (RREC) near Stuttgart, Ark., 2021.

Entry	Pedigree	Grain Type[†]	Grain Yield PTRS	RREC1[‡]	RREC2	Mean	%HR/%TR[§]
			--------------(bu./ac)--------------				
21CAYT01	CLL15	CL	239	217	194	216	58/65
21CAYT02	CLL16	CL	252	226	210	229	57/65
21CAYT03	CLL17	CL	244	208	170	207	59/65
21CAYT04	CLM04	CM	245	210	184	213	62/65
21CAYT05	CLJ01	CLJ	200	178	164	180	62/68
21CAYT06	RU1102034/CL172	CL	262	222	202	229	59/67
21CAYT07	RU1302048/CL151	CL	263	243	201	236	56/64
21CAYT08	ROYJ*2/RU1401133	CL	201	222	203	209	57/67
21CAYT09	CTHL/CL172	CL	227	216	202	215	56/66
21CAYT10	RU1102034/RU1501024*2	CL	247	216	210	224	60/65
21CAYT11	RICO/BNGL//RU1202068	CM	241	228	205	225	57/65
21CAYT12	JSMN/DLLA//DLLA/3/JZMN/4/	CLJ	225	215	188	209	57/64
21CAYT13	14SIT818/RU1501096	CM	258	233	215	235	59/64
21CAYT14	MRMT/4/9502008-A/DREW/3/	CL	179	198	177	185	60/68
21CAYT15	MRMT/RU1501185	CL	231	202	176	203	60/67
21CAYT16	RU1102034/RU1501024	CL	233	196	196	209	59/66
21CAYT17	RU1302048/CL151	CL	251	238	191	226	60/68
21CAYT18	CL172/RU1102034	CL	243	224	211	226	59/65
21CAYT19	RU1501050/RU1501027	CM	253	247	226	242	59/65
21CAYT20	ROYJ*2/14CSIT203	CL	233	218	201	217	58/67
21CAYT21	RU1301030/14CSIT314	CM	234	213	176	208	62/66
21CAYT22	ROYJ/CL111	CL	235	206	194	211	58/65
21CAYT23	CL271/JPTR	CM	244	217	186	216	59/65
21CAYT24	CFFY/15CSIT749	CM	257	205	149	204	61/66
21CAYT25	EARL/9902028//RU1202068	CM	251	247	202	233	61/66
21CAYT26	16ARPT271/RU1601050	CM	234	235	208	226	62/66
21CAYT27	16AYT054/15CSIT771	CM	231	214	167	204	61/66
21CAYT28	JPTR/TITN//15CSIT769	CM	244	235	195	225	61/65
21CAYT29	RU1601124/RU1601096	CL	203	182	161	182	58/67
21CAYT30	RU1202137/RU1501024	CL	230	203	178	204	57/65

Continued

Table 2. Continued.

Entry	Pedigree	Grain Type[†]	Grain Yield PTRS	RREC1[‡]	RREC2	Mean	%HR/%TR[§]
			----------------(bu./ac)---------------				
21CAYT31	RU1401136/CL172	CL	229	204	173	202	56/66
21CAYT32	DMND/RU1601130	CL	225	215	191	210	55/67
21CAYT33	RU1601167/DMND	CL	234	213	203	217	59/66
21CAYT34	DMND/RU1601167	CL	236	195	204	211	57/64
21CAYT35	RU1102034/CL172	CL	230	208	208	215	57/64
21CAYT36	RU1102192/CL172	CL	244	216	201	220	59/65
21CAYT37	NPTN/RU1501096	CM	223	219	166	203	59/62
21CAYT38	RU1102131/14CSIT203	CL	249	188	174	204	59/66
21CAYT39	CL151/CL153	CL	215	199	168	194	60/66
21CAYT40	DMND/RU1701096	CL	260	241	207	236	59/67
c.v.(%)[¶]			6.1	n/a	4.3	5.5	2.9/1.6
$LSD_{0.05}$			21.6	n/a	13.4	12.8	1.6/1.0

[†] Grain type, CL = Clearfield® long-grain, CLJ = Clearfield® jasmine-type long-grain, and CM = Clearfield® medium-grain.

[‡] RB1 = planted on 5 April and RB2 = planted on 13 May.

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

[¶] Coefficient of variance.

Table 3. Grain and milling yields of 50 Provisia® (PV) long-grain breeding lines and commercial checks in the advanced PV elite line yield trial (PAYT) conducted at University of Arkansas System Division of Agriculture's Pine Tree Research Station (PTRS) near Colt, Ark., and Rice Research and Extension Center (RREC) near Stuttgart, Ark., 2021.

		Grain Yield			
Entry	Pedigree	PTRS	RREC	Mean	%HR/%TR[†]
		-----------(bu./ac)-----------			
21PSIT2001	RU1601121/HPHI2//RU1102034	205	171	188	54/65
21PSIT2002	17SIT530//17SIT636/HPHI2	214	171	192	55/66
21PSIT2003	(RU1102131/RU1401185)*2/HPHI2	191	166	179	51/64
21PSIT2004	18AYT62/RU1201145//HPHI2/3/RU1701084/…	213	192	203	54/65
21PSIT2005	(RU1102131/RU0903141)*2/HPHI2	138	133	135	54/65
21PSIT2006	(RU1102131/RU0903141)*2/HPHI2//RU0902125/	194	209	201	49/63
21PSIT2007	(RU1102131/RU0903141)*2/HPHI2//RU0902125/	191	161	176	48/63
21PSIT2008	(RU1102034/CTHL)*3/HPHI2	172	187	180	59/66
21PSIT2009	(ROYJ/RU1102034)*2/HPHI2//ROYJ/RU0902140	179	166	172	51/63
21PSIT2010	(ROYJ/RU1102034)*2/HPHI2//ROYJ/RU0902140	173	170	171	53/63
21PSIT2011	(ROYJ/RU1102034)*2/HPHI2//ROYJ/RU0902140	184	170	177	56/64
21PSIT2012	(RU1102131/RU0903141)*2/HPHI2//ROYJ/…	124	124	124	55/65
21PSIT2013	(RU1102131/RU0903141)*2/HPHI2//ROYJ/…	181	156	169	52/62
21PSIT2014	(RU1102131/RU0903141)*2/HPHI2//ROYJ/…	202	196	199	56/65
21PSIT2015	(ROYJ/RU1102034)*2/HPHI2	208	191	200	54/65
21PSIT2016	(ROYJ/RU1102034)*2/HPHI2	215	196	205	53/65
21PSIT2017	(RU1102131/RU0903141)*3/HPHI2	177	194	185	57/66
21PSIT2018	(RU1102131/RU0903141)*3/HPHI2	194	181	188	56/65
21PSIT2019	(RU1102131/RU0903141)*3/HPHI2	198	198	198	58/65
21PSIT2020	(RU1102131/RU0903141)*3/HPHI2	188	211	200	56/64
21PSIT2021	(RU1102131/RU0903141)*3/HPHI2	189	189	189	57/64
21PSIT2022	(RU1102131/RU0903141)*3/HPHI2	194	183	188	56/64
21PSIT2023	(RU1102131/RU0903141)*3/HPHI2	222	201	211	56/66
21PSIT2024	(RU1102131/RU0903141)*3/HPHI2	194	186	190	55/64
21PSIT2025	(RU1102131/RU0903141)*3/HPHI2	182	188	185	57/65
21PSIT2026	(RU1102131/RU0903141)*3/HPHI2	197	178	187	56/64
21PSIT2027	(RU1102131/RU0903141)*3/HPHI2	194	184	189	56/65
21PSIT2028	(RU1102131/RU0903141)*3/HPHI2	191	197	194	56/64
21PSIT2029	(RU1102131/RU0903141)*3/HPHI2	190	193	192	56/64
21PSIT2030	(RU1102131/RU0903141)*3/HPHI2	183	171	177	54/64
21PSIT2031	(RU1102131/RU0903141)*3/HPHI2	190	185	188	57/65
21PSIT2032	(RU1102131/RU0903141)*3/HPHI2	169	179	174	55/65
21PSIT2033	(RU1102131/RU0903141)*3/HPHI2	208	203	205	53/64
21PSIT2034	(RU1102131/RU0903141)*3/HPHI2	188	187	187	57/65
21PSIT2035	(RU1102131/RU0903141)*3/HPHI2	214	211	212	54/65

Continued

Table 3. Continued.

Entry	Pedigree	Grain Yield PTRS	Grain Yield RREC	Grain Yield Mean	%HR/%TR[†]
		-----------(bu./ac)-----------			
21PSIT2036	(RU1102131/RU0903141)*3/HPHI2	198	197	198	56/64
21PSIT2037	(RU1102131/RU0903141)*3/HPHI2	197	202	200	58/66
21PSIT2038	(RU1102131/RU0903141)*3/HPHI2	198	179	188	56/65
21PSIT2039	(RU1102131/RU0903141)*3/HPHI2	174	175	175	54/63
21PSIT2040	(RU1102131/RU0903141)*3/HPHI2	184	179	182	55/64
21PSIT2041	(RU1102131/RU0903141)*3/HPHI2	205	193	199	53/63
21PSIT2042	(RU1102131/RU0903141)*3/HPHI2	202	172	187	53/63
21PSIT2043	(RU1102131/RU0903141)*3/HPHI2	192	187	190	56/65
21PSIT2044	(RU1102131/RU0903141)*3/HPHI2	197	194	195	55/65
21PSIT2045	(RU1102131/RU0903141)*3/HPHI2	183	193	188	58/65
21PSIT2046	(RU1102131/RU0903141)*3/HPHI2	187	208	198	55/65
21PSIT2047	17SIT530//17SIT636/HPHI2	172	147	160	58/64
21PSIT2048	PVL02	209	174	191	62/69
21PSIT2049	PVL03	200	200	200	56/67
21PSIT2050	Check3	266	190	228	56/66
c.v.(%)[‡]		5.7	4.8	5.4	2.6/1.4
$LSD_{0.05}$		17.6	14.0	11.5	1.6/1.0

† Coefficient of variance

‡ Milling yield, HR = head rice and TR = total rice yield.

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

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Abstract

Reflecting recent changes in 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. In order 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 of medium-grain rice was grown annually, making up about 13% of total state rice acreage (USDA-ERS, 2021). Even with the rapid adoption of hybrid rice from the private sector during the last two decades, about 20% of 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 great yield advantage over conventional pure-line varieties (Walton, 2003). However, further improvement of hybrid rice is critically needed to address its inconsistent milling yield, poor 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 the development of 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 resistance, blast resistance, and physicochemical characteristics. Meanwhile, genomic selection will be attempted on reasonable uniform mid-generation breeding lines. 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 great number of traits will be considered during this stage of selection, including grain quality (shape and appearance), plant type, short 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. Milling evaluation of small size samples, as well as physicochemical analysis by Riceland Foods Research and Technology Center, will be conducted to eliminate lines with evident quality problems in order to maintain the standard U.S. rice quality of different grain types/market classes. Yield evaluations include the Stuttgart Initial Yield Trial (SIT), Clearfield® SIT (CSIT), and Provisia® SIT (PSIT) at RREC, the Advanced Elite Line Yield Trial (AYT), Clearfield AYT (CAYT), and Provisia AYT (PAYT) at RREC, Pine Tree Research Station (PTRS) near Colt, Ark., and Northeast Research and Extension Center (NEREC) in Keiser, Ark. Advanced yield trials include the Arkansas Rice Variety Advancement Trials (ARVAT) and on-farm Arkansas Rice Performance Trials (ARPT) conducted

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by Dr. Jarrod Hardke, the Arkansas rice agronomy specialist, at 6–10 locations in rice-growing regions across the state, and the Cooperative Uniform Regional Rice Nursery (URRN) conducted in cooperation with public rice breeding programs in 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 2021 included 1,523 transplanted or drill-seeded F_1 populations, 1,223 space-planted F_2 populations, and 61,600 panicle rows ranging from F_3 to F_7. Visual selection on approximately 1 million individual space-planted F_2 plants resulted in a total of 50,000 panicles that will be individually processed and grown as F_3 panicle rows in 2022. A total of 5,506 panicle rows were selected for advancement to the next generation, while 1,650 rows appeared to be uniform and superior to others and therefore were bulk-harvested by hand as candidates for 2022 SIT, CSIT, and PSIT trials. In 2021 CSIT, we evaluated 346 new breeding lines, which included 281 CL long-grain and 65 CL medium-grain breeding lines. Of 468 new conventional breeding lines tested in the SIT trial, 415 were long-grain lines, 51 medium-grain lines, and 2 short-grain lines. Molecular marker-assisted selection (MAS) was conducted on 763 samples, including preliminary yield trial entries, Provisia® (PV) backcrosses or 3-way crosses, bulked F_3 rows, and panicles for seed purity by using 8 SSR and SNP molecular markers for physicochemical characteristics, blast resistance, and herbicide resistance. An 80-entry Advanced Elite Line Yield Trial (AYT) was conducted at NEREC and PTRS in addition to RREC, while a 40-entry CAYT and a 50-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 2021 SIT, CSIT, and PSIT trials (Tables 1–5). Twenty-eight advanced experimental lines were evaluated in the multi-state URRN and statewide ARVAT and ARPT trials. The results of those entries and selected check varieties are listed in Table 6. Three Puerto Rico winter nurseries consisting of 15,000 7-foot rows were planted, selected, and turned around during offseason 2021 and will be harvested in spring 2022. The first-ever one-acre breeder seed production of recently released conventional long-grain variety Ozark was conducted in Puerto Rico in mid-November and will be harvested in April 2022. A total of 903 new crosses were made to incorporate desirable traits from multiple sources into adapted Arkansas rice genotypes, which included 221 PV long-grain, 9 PV medium-grain, 208 CL long-grain, 96 CL medium-grain, 264 conventional long-grain, 98 conventional medium-grain, and 2 S line crosses.

The conventional, traditional stature long-grain line RU2001185 and conventional semi-dwarf medium-grain line RU1901033 continued having outstanding performance in the 2021 trials and were officially released as Ozark and Taurus, respectively. A ramped-up foundation seed production of both new releases is underway and will continue throughout 2022. One hundred fifty 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 2022 advanced yield trials, including ARVAT, AYT, ARPT, PC, and URRN.

Practical Applications

Successful development of medium-grain varieties Titan, CLM04, Lynx, and Taurus and the long-grain variety 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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Literature Cited

USDA-ERS. 2021. 2020 United States Department of Agriculture-Economic Research Service. Rice Yearbook. Available at https://www.ers.usda.gov/data-products/rice-yearbook/

Walton, M. 2003. Hybrid rice for mechanized agriculture. *In*: Virmani, S.S., Mao, C.X. and Hardy B. (eds) Hybrid Rice for Food Security, Poverty Alleviation, and Environmental Protection. International Rice Research Institute, Los Banos, Philippines. pp. 97-102.

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, Ark., 2021.

Variety/Line	Pedigree	Seedling vigor[a]	Days to 50% heading	Plant height	Yield	Milling yields Head rice	Milling yields Total rice
				(cm)	(bu./ac)	(%)	(%)
21CSIT1181[b]	16AYT045/CL172	3.0	89	101	244	54.2	65.1
21CSIT1127[b]	DMND/RU1601127	3.0	93	105	230	59.9	66.3
21CSIT1009[b]	RU1801169/LKST	3.0	89	100	228	51.9	62.9
21CSIT1021[b]	RU1801169/DMND	3.0	88	98	222	56.5	64.7
21CSIT1042[b]	RU1102128/RU1501024	4.0	89	95	222	55.9	62.9
21CSIT1071[b]	RU1601167/CL172	4.0	88	102	222	51.9	61.4
21CSIT1008[b]	RU1801169/LKST	3.0	89	102	219	54.2	65.1
21CSIT1192[c]	RU1801169/JEWL	3.0	83	108	217	61.1	66.3
21CSIT1356[c]	14CSIT203/DMND	3.5	78	100	215	54.5	64.3
21CSIT1340[c]	RU1701185/17AYT026	3.0	77	99	214	54.4	63.6
21CSIT1281[c]	RU1201111/CL172	3.0	82	99	212	61.1	66.3
CLL15[b]	CLL15	3.0	91	101	220	58.6	65.1
CLL16[b]	CLL16	3.0	94	112	200	55.4	63.9
CLL16[c]	CLL16	3.0	86	112	203	57.9	65.5
CLL17[b]	CLL17	3.0	92	106	204	58.5	64.5

[a] A subjective 1–7 rating taken at emergence, 1 = perfect stand and 7 = no stand.
[b] Planted on 5 April.
[c] Planted on 13 May.

Table 2. Performance of selected Clearfield medium-grain experimental lines and check varieties in Clearfield® Stuttgart Initial Trial (CSIT) at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center near Stuttgart, Ark., 2021.

Variety/Line	Pedigree	Seedling vigor[a]	Days to 50% heading	Plant height	Yield	Milling yields (%) Head rice	Milling yields (%) Total rice
				(cm)	(bu./ac)	(%)	(%)
21CSIT1057[b]	RU1501050/RU1501027	3.5	92	95	227	52.9	62.7
21CSIT1048[b]	CFFY/RU1501027	4.0	92	103	227	52.1	64.4
21CSIT1051[b]	TITN/RU1501096	4.0	87	103	219	57.3	62.3
21CSIT1246[c]	NPTN/RU1501027	3.0	84	99	214	64.3	67.0
21CSIT1256[c]	16ARPT271/15CSIT769	3.0	81	105	210	52.3	63.0
21CSIT1252[c]	16ARPT269/RU1601050	3.0	81	101	210	60.8	64.2
21CSIT1052[b]	TITN/RU1501096	3.5	87	99	210	56.7	61.9
21CSIT1102[b]	16ARPT269/CLM04	4.0	93	102	205	59.1	63.0
21CSIT1294[c]	RU1601050/CFFY	3.0	80	95	205	54.0	64.7
CLM04[b]	CLM04	3.0	92	109	210	61.1	63.9
CLM04[c]	CLM04	3.0	81	103	174	61.1	65.0

[a] A subjective 1–7 rating taken at emergence, 1 = perfect stand and 7 = no stand.
[b] Planted on 5 April.
[c] Planted on 13 May.

Table 3. Performance of selected conventional medium-grain experimental lines and check varieties in Stuttgart Initial Trial (SIT) at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center near Stuttgart, Ark., 2021.

Variety/Line	Pedigree	Seedling vigor[a]	Days to 50% heading	Plant height	Yield	Milling yields Head rice	Total rice
				(cm)	(bu./ac)	(%)	(%)
21SIT204[c]	16ARPT269/16ARPT272	3.0	88	95	264	63.3	67.3
21SIT210[c]	16ARPT272/RU1501050	3.0	86	98	258	53.9	65.6
21SIT194[c]	TITN/EARL	3.0	84	96	258	n/a	n/a
21SIT001[b]	RU1701124/JPTR	3.5	91	100	237	56.7	65
21SIT039[b]	RU1501050/07PY828	4.5	89	102	221	38.2	61.5
21SIT037[b]	CFFY/07PY826	3.0	93	107	219	59.3	64.2
21SIT032[b]	JPTR/14SIT891	4.0	95	92	214	n/a	n/a
21SIT049[b]	TITN/07SP290	3.0	89	103	207	n/a	n/a
Jupiter[c]	Jupiter	3.0	86	99	224	63.2	65.7
Taurus[c]	Taurus	3.0	84	99	266	64.2	68.4
Lynx[b]	Lynx	3.0	93	106	220	n/a	n/a

[a] A subjective 1–7 rating taken at emergence, 1 = perfect stand and 7 = no stand.
[b] Planted on 5 April.
[c] Planted on 12 April.

Table 4. Performance of selected conventional long-grain experimental lines and check varieties in Stuttgart Initial Trial (SIT) at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center near Stuttgart, Ark., 2021.

Variety/Line	Pedigree	Seedling vigor[a]	Days to 50% heading	Plant height	Yield	Milling yields Head rice	Total rice
				(cm)	(bu./ac)	(%)	(%)
21SIT259[d]	RU1201111/DMND	3.0	84	112	275	53.7	66.9
21SIT368[d]	17AYT06/RU1401099	3.7	83	115	272	45.3	63.2
21SIT311[d]	17AYT06/FRNS	3.5	85	115	266	60.7	68.7
21SIT407[d]	RU1601070/DMND	3.0	85	112	265	55.6	66.5
21SIT327[d]	17AYT06/RU1601070	3.0	85	114	264	43.9	65.8
21SIT268[d]	DMND/RU1201111	4.0	85	115	263	57.9	67.2
21SIT401[d]	JEWL/RU1601070	3.3	88	114	263	51.2	67.4
21SIT227[c]	DMND/LKST	4.0	87	117	259	50.7	67.4
21SIT516[d]	RU1201111/DMND	3.0	84	108	258	n/a	n/a
21SIT423[d]	DMND/RU1201145	3.0	83	106	248	57.5	66.1
21SIT061[b]	RU1501030/DMND	3.0	91	104	239	55.5	67.1
21SIT132[b]	DMND/RU1201111	3.0	91	111	238	48.9	66.1
Diamond[b]	Diamond	3.0	92	114	218	n/a	n/a
Ozark[d]	Ozark	3.5	86	118	243	n/a	n/a
Diamond[d]	Diamond	3.0	85	114	227	n/a	n/a

[a] A subjective 1–7 rating taken at emergence, 1 = perfect stand and 7 = no stand.
[b] Planted on 5 April.
[c] Planted on 12 April.
[d] Planted on 26 April.

Table 5. Performance of selected Provisia (PV) long-grain experimental lines and check varieties in PV Stuttgart Initial Trial (PSIT) at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center near Stuttgart, Ark., 2021.

Variety/Line	Pedigree	Seedling vigor[a]	Days to 50% heading	Plant height	Yield	Milling yields Head rice	Milling yields Total rice
				(cm)	(bu./ac)	(%)	(%)
21PSIT2147	(RU1102131/RU0903141)*3/HPHI2	3.0	85	99	229	n/a	n/a
21PSIT2081	(RU1102131/RU0903141)*2/HPHI2// RU0902125/RU1102034	3.5	82	100	220	n/a	n/a
21PSIT2076	(RU1102131/RU0903141)*3/HPHI2	3.3	84	106	216	57.2	66.2
21PSIT2143	(ROYJ/RU1102034)*2/HPHI2	3.0	75	93	211	n/a	n/a
21PSIT2165	(RU1102131/RU0903141)*3/HPHI2	3.0	85	104	210	51.7	63.4
21PSIT2057	(RU1102131/RU0903141)*3/HPHI2	3.0	83	105	210	53.8	63.2
21PSIT2059	(RU1102131/RU0903141)*3/HPHI2	3.0	83	107	205	54.7	63.8
21PSIT2061	(RU1102131/RU0903141)*3/HPHI2	3.0	83	105	203	53.3	63.2
PVL02	PVL02	3.0	80	109	185	n/a	n/a
PVL03	PVL03	3.0	85	103	202	57.8	66.5

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

Table 6. Average yield, milling, and agronomic characteristics of selected experimental long-grain and medium-grain lines and check varieties tested in the Uniform Regional Rice Nursery (URRN) in Arkansas, Louisiana, Mississippi, and Texas, 2021.

Entry	Pedigree	Grain type[a]	Days to 50% heading	Plant height	Yield	Milling yields Head rice	Milling yields Total rice
				(cm)	(bu./ac)	(%)	(%)
RU2101234	EARL/PI350298//JPTR/3/RU1501096	CM	92	101	244	56.1	67.2
RU2101113	RICO/BNGL///RU0502137	M	91	100	239	60.7	68.5
RU1901165	RU1001067/RU0602171	M	91	91	236	59.2	68.1
RU1801238	EARL/9902028//RU1202068	CM	95	93	235	55.3	69.6
RU2101125	RU1801173/RU1601070	L	93	109	232	54.5	69.5
RU2101221	RU1102034/RU1501024*2	CL	91	108	230	60.6	69.9
RU1901129	RU1102131/14CSIT203	CL	94	97	230	62.8	71.0
RU2101208	JSMN/DLLA//DLLA/3/JZMN/4/RU1201025	CL(A)	93	106	228	59.2	69.5
RU2001121	RU1102131/14CSIT203	CL	91	99	227	56.7	70.4
RU2101137	DMND/JEWL	L	89	108	221	48.4	68.3
Taurus	Taurus	M	88	91	229	56.9	69.6
Lynx	Lynx	M	92	106	212	52.9	68.0
Jupiter	Jupiter	M	93	97	212	62.0	67.9
Titan	Titan	M	86	101	210	53.7	68.7
CLL16	CLL16	CL	93	108	234	50.1	68.1
CLM04	CLM04	CM	92	107	227	57.9	69.1
Ozark	Ozark	L	89	107	215	51.2	69.0
Diamond	Diamond	L	89	103	209	48.3	68.8

[a] CL = Clearfield® long-grain, CL(A) = Clearfield® aromatic long-grain, CM = Clearfield® medium-grain, L = long-grain, and M = medium-grain.

ARoma 22, an Aromatic Jasmine-type, Long-Grain Rice Variety

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Abstract

ARoma 22 is a new high-yielding, mid-season, jasmine-type aromatic long-grain rice cultivar derived from the cross Jazzman//Drew/PI 637517/3/Taggart. The aromatic line was developed by the University of Arkansas System Division of Agriculture's Arkansas Agricultural Experiment Station and has been approved for release for the 2022 growing season. ARoma 22 offers a jasmine-type rice adapted to Arkansas growing conditions for rice producers who wish to serve the aromatic rice consumer market.

Introduction

ARoma 22 was developed in the rice improvement program at the University of Arkansas System Division of Agriculture's (UADA) Rice Research and Extension Center (RREC), near Stuttgart, Arkansas, and has been released for the 2022 growing season. ARoma 22 has a good milling yield, conventional plant height, and is mid-season in maturity. ARoma 22 was developed to meet the demand of consumers desiring an aromatic rice grown in Arkansas and the southern U.S rice-growing regions. ARoma 22 was advanced using rice grower check-off funds distributed by the Arkansas Rice Research and Promotion Board.

Procedures

ARoma 22 rice (*Oryza sativa* L.) is a high-yielding, mid-season, jasmine-type aromatic long-grain rice cultivar developed by the Arkansas Agricultural Experiment Station (AAES). ARoma 22 originated from the cross Jazzman//Drew/PI 637517/3/Taggart (cross number 20123405), made at the RREC in 2012. The name, ARoma 22, was derived from the two-letter designation of Arkansas (AR), the fact that the line is aromatic, and selected for release in 2022. The experimental designation for early evaluation of ARoma 22 was STG16L-15-043, starting with a bulk of F_5 seed from the 2016 panicle row L-15-043. ARoma 22 was tested in the Arkansas Rice Performance Trials (ARPT) from 2020 to 2021 and in the Cooperative Uniform Regional Rice Nursery (URRN) from 2019 to 2021 as entry RU1901231 (RU number specifies Cooperative Uniform Regional Rice Nursery; 19 recognizes the year entered was 2019; 01 is the Stuttgart, Ark. designation; and 231 identifies the entry number).

In 2020, the ARPT was conducted at five locations in Arkansas: the 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.; a Clay County producer field (CLAY) near Corning, Ark.; and a Desha County producer field (DESHA) near McGehee, Ark. In 2021, the tests were conducted at four locations in Arkansas: RREC, PTRS, NEREC, and Northeast Rice Research and Extension Center (NERREC), near Jonesboro, Ark. The yield trial had four replications per location to reduce soil heterogeneity effects and to decrease the amount of experimental error. The URRN multi-state yield trials were conducted with three replications at the following locations: RREC; Stoneville, Miss.; Beaumont, Texas; Crowley, La.; and Malden, Mo. Data collected from these trials included plant height, maturity, lodging, percent head rice, percent total rice, grain yield (adjusted to 12% moisture), and disease reaction information. Cultural practices varied to some extent among locations, but overall, the trials were grown under conditions of high productivity as recommended by the UADA Cooperative Extension Service Rice Production Handbook MP192 (CES, 2021). Agronomic and milling data are presented in Tables 1 and 2. Disease ratings, which are indications of potential damage under conditions favorable for the development of specific diseases, have been reported on a scale from 0 = least susceptible to 9 = most susceptible, or as very susceptible (VS), susceptible (S), moderately susceptible (MS), moderately resistant (MR), and resistant (R). Straw strength is a relative estimate based on observations of lodging in field trials using the scale from 0 = very strong straw to 5 = very weak straw, totally lodged.

Results and Discussion

Rough rice grain yields of ARoma 22 have been favorable in the ARPT. In 9 ARPT yield trials from 2020 to 2021, the average yield of ARoma 22 was 170 bu./ac (Table 1). Data from the URRN conducted in Arkansas from 2019 to 2021 showed ARoma 22 had an average grain yield of 159 bu./ac (Table 3). Milling yields (%whole kernel/%total milled rice) from 2020 ARPT averaged 64/71 for ARoma 22 (Table 1). Milling yield reports from the Arkansas URRN yield trials from 2019 to 2020 averaged 62/70 for ARoma 22 (Table 3).

ARoma 22 is a mid-season variety reaching 50% heading at 87 days on average, according to Arkansas URRN data from 2019 to 2021 (Table 3). ARoma 22 has excellent straw strength,

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receiving a 1.0 rating according to 2020 ARPT data. The plant height of ARoma 22 ranges from 38 to 43 in. and the canopy height is 38 in. (Table 1). Results of the analysis to determine the level of the compound 2-acetyl-1-pyrroline (2AP), which quantifies aroma in rice, showed ARoma 22 having a high level of 2AP at 431 ng/g (Testing conducted by L. Howard, UADA, Food Science in 2019).

ARoma 22 is moderately susceptible to common races of rice blast (*Pyricularia grisea* (Cooke) Sacc.), sheath blight (*Rhizoctonia solani* Kühn), and bacterial panicle blight (*Burkholderia glumae*) using the standard disease ratings R = resistant, MR = moderately resistant, MS = moderately susceptible, S = susceptible, and VS = very susceptible to disease. Under high nitrogen fertilization, ARoma 22 is moderately susceptible to false smut (*Ustilaginoidea virens* (Cooke) Takah). Reactions to straighthead, narrow brown leaf spot, stem rot, black sheath rot, and sheath spot are unknown at the time of this writing.

Plants of ARoma 22 have erect culms, green erect leaves, and pubescent lemma, palea, and leaf blades. The lemma and palea are straw-colored with purple apiculi, many of which fade to straw at maturity. The average individual kernel length of ARoma 22 is 7.5 mm and the milled kernel weight averaged 22.3 g/1,000 seeds in the 2020 ARPT (5 locations, 2 reps/test), as found in Table 2.

The endosperm of ARoma 22 is nonglutinous, aromatic, and covered by a light brown pericarp. Rice quality parameters indicate that ARoma 22 has jasmine-type characteristics (Webb et al., 1985). ARoma 22 has an average apparent starch amylose content of 16.4 g/kg and the intermediate gelatinization temperature is listed as 61.9 °C, according to data provided by Riceland Quality Laboratory (Table 2).

Practical Applications

The release of ARoma 22 provides rice growers with a high-yielding, jasmine-type aromatic, mid-season, long-grain rice. The major advantages of ARoma 22 are its preferred aesthetics to consumers and its high yield potential in the specialty aromatic market.

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Literature Cited

CES. 2021. Cooperative Extension Service. Arkansas Rice Production Handbook. J.T. Hardke (ed). University of Arkansas System Division of Agriculture, MP 192, Little Rock, Ark.

Webb, B.D., C.N. Bollich, H.L. Carnahan, K.A. Kuenzel, and K.S. McKenzie. 1985. Utilization characteristics and qualities of United States rice. p. 25-35. In: Rice grain quality and marketing. IRRI, Manila Philippines.

Table 1. Yield and agronomic data of ARoma 22 from the Arkansas Rice Performance Trials, 2020 to 2021.

Cultivar	Yield[a] 2020	Yield[a] 2021	Yield[a] Mean	Height[b]	50% Heading	Milling[c]
	------------------(bu./ac)------------------			(in.)	(days)	(%HR/%TOT)
ARoma 22	167	173	170	38.2	90	64/71

[a] Yield trials in 2020 were conducted at Rice Research and Extension Center (RREC), near Stuttgart, Ark.; Pine Tree Research Station (PTRS), near Colt, Ark.; Northeast Research and Extension Center (NEREC), near Keiser, Ark.; Clay County producer field (CLAY), near McDougal, Ark.; Desha County producer field (DESHA), near McGehee, Ark. In 2021, trials were conducted at RREC; PTRS; NEREC; and Northeast Rice Research and Extension Center (NERREC), near Jonesboro, Ark.

[b] Canopy height and heading data collected from 2020 to 2021.

[c] Milling figures are %head rice/%total milled rice data collected from 2020 yield trials and analyzed at Riceland Grain Quality Laboratory. Milling data presented from RREC, NEREC, PTRS, CLAY, and DESHA.

Table 2. Agronomic data of ARoma 22 from the Arkansas Rice Performance Trials, 2020 to 2021.[a]

Cultivar	Amylose[b]	Gel Temp[b]	Kernel Length[b]	Kernel Width[b]	Kernel Thickness[b]	Kernel Weight[b]	Chalk[b]
	(%)	(°C)	(mm)	(mm)	(mm)	(mg)	(%)
ARoma 22	16.36	61.94	7.50	2.14	1.70	22.3	1.01

[a] Trials in 2020 were conducted at Rice Research and Extension Center (RREC) near Stuttgart, Ark.; Pine Tree Research Station (PTRS), near Colt, Ark.; Northeast Research and Extension Center (NEREC), near Keiser, Ark.; Clay County producer field (CLAY), near McDougal, Ark.; Desha County producer field (DESHA), near McGehee, Ark. In 2021, trials were conducted at RREC; PTRS; NEREC; and Northeast Rice Research and Extension Center (NERREC), near Jonesboro, Ark.

[b] Milling data presented from RREC, NEREC, PTRS, CLAY, and DESHA.

Table 3. Yield and agronomic data of ARoma 22 from the Arkansas Uniform Regional Rice Nursery, 2019 to 2021.

Cultivar	Yield[a] 2019	Yield[a] 2020	Yield[a] 2021	Yield[a] Mean	Height[b]	50% Heading	Milling[c]
	--------------------------(bu./ac)--------------------------				(in.)	(days)	(%HR/%TOT)
ARoma 22	149.6	156.0	171.7	159.1	43.4	87	62/70

[a] Arkansas = University of Arkansas System Division of Agriculture Rice Research and Extension Center, Stuttgart, Ark.

[b] Height data collected from ground to panicle tip.

[c] Milling figures are %head rice/%total milled rice data collected in 2019 and 2020 yield trials.

Rice Breeding and Pathology Technical Support

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Abstract

Obtaining disease resistance data is necessary for preliminary and advanced breeding lines and newly developed rice varieties. Disease resistance is a valuable characteristic that rice breeders place a tremendous effort towards at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC) near Stuttgart, Ark. 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 using artificial inoculation for sheath blight at the RREC. Assessment for neck blast is conducted at the University of Arkansas System Division of Agriculture's Pine Tree Research Station (PTRS) near Colt, Ark., 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 dispersal methods that have explicit protocols. Data generated from screening helps in the selection of 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 extension plant pathology programs with 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 known major diseases begins in the early generations of selection and is considered necessary for a successful breeding program. Lines having potential disease resistance but not meeting the desired agronomic levels for release can become parents to develop other new varieties.

Rice blast, caused by *Magnaportha grisea* (T.T. Herbert) M.E. Barr, is still a damaging disease in severe disease years, causing significant yield loss. Emphasis is given to evaluating breeding materials for both leaf and neck/panicle 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/panicle blast. Screening of rice in the greenhouse and field for blast disease requires favorable environmental conditions preceding and following inoculation of the pathogen.

All advanced breeding lines and selected preliminary breeding lines are assessed in the field at RREC for sheath blight (*Rhizoctonia solani* Kuhn), another devastating fungal disease of rice. To date, genes have not been identified that render complete resistance to this pathogen. However, through the endeavors of artificial inoculation, newly developing rice lines have been recognized with improved tolerance to *R. solani*.

Procedures

Evaluation of Breeding Materials for Blast Resistance in the Greenhouse

Entries of the Cooperative Uniform Regional Rice Nursery (URRN), Arkansas Rice Performance Trials (ARPT), Aromatic Arkansas Yield Trials (ARO AYT), Aromatic Stuttgart Initial Tests (ARO SIT), Advance, Imidazolinone Advance (IMI-ADV), Stuttgart Initial Trials (SIT), and Imidazolinone Stuttgart Initial Test (IMI-SIT) were evaluated for their resistance to leaf blast. Tests were replicated to generate three disease observations per entry. Over 300 flats of soil were prepared to produce 3- to 4-leaf seedlings planted as hill plots. Each replicate of the URRN, ARPT, Advance, IMI-ADV, IMI-SIT, and Aromatics were spray-inoculated using individual spore suspensions made of *M. grisea* races: IB-1, IB-17, IB-49, IC-17, and IE-1K. 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 to score relative amounts of lesion coverage, i.e., 1 (single leaf or lesion) to 100 (all leaves necrotic with multiple lesions). A "bulk" spore suspension was prepared using a combination of the aforementioned races (minus IE-1K) for preliminary lines (referred to as SIT and IMI-SIT entries) and applied the same spray inoculation method as that for individual races. IE-1K was sprayed separately due partially to the severe effect of this race on rice.

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

For sheath blight tolerance, a nursery at the RREC was planted on 7 May as two adjacent bays. Five replications of the same entries of all tests used in the greenhouse blast assessment were planted for a total of 1,000 hill plots per replication. On 13 July, plants (at panicle initiation stage) were hand-inoculated with a mixture of two relatively slow-growing *R. solani* isolates (approximately 20 gallons) at the rate of 24 g (~1 oz) per six hill plot row. In addition,

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a subset of 69 entries from the previous year's ARPT and URRN tests that included tolerant and susceptible disease reactions with "slow" growing fungal isolates were planted in 10 replication sets. Half the sets were hand-inoculated with "slow" growing isolates, while the other half received the "fast" growing *R. solani* isolates. About six weeks later, a fungal disease assessment of each hill plot was carried out using a rating scale of 0 (no disease) to 9 (severe disease that reached the flag leaf).

The nursery to evaluate blast disease at PTRS was established on 14 May in a secluded area having a forested border on three sides of the test. For a possible windbreak, corn was planted on the remaining open side to enclose the test entirely. The study included 288 entries from the ARPT/URRN collection in six replicated hill plots 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 with intermittent flushing. Around 100 gallons of corn chops/rough rice media was prepared using a mixture of four of the pathogen races used in greenhouse leaf blast assessment that are common to Arkansas. IE-1K was omitted since there has not been any recorded evidence of this race in St. Francis county. The nursery was inoculated four times over the course of the season: 9 July (tillering), 22 July (after panicle differentiation), 17 August (boot split), and 25 August (early heading). The semi-dried seed media was broadcast to inoculate rice plant entries and spreader materials. Unfortunately, data was not collected due to severe wild boar damage in the nursery.

Assistance to Extension Rice Pathology

Breeding pathology technical support assisted with the planting of 6 field experiments designed to collect data for rice disease suppression/control of early season seedling and sheath blight diseases. Approximately 25 gallons of *R. solani* AG1-1A inoculum were prepared and applied to 104 rice plots tested against 29 fungicide efficacy treatments. Industry seed treatment studies also entailed a 40 g/plot of *R. solani* AG9 and 40 g of Pythium/plot rate added to 2 separate sets of 22 envelopes containing a measured amount of seed/plot with fungicide treated seed. These 44 envelopes were then planted for one of eight seed dressing fungicide treatments. An additional 12-plot biocontrol spray study was also established to evaluate the use of a bacterium to control rice seedling diseases. Both stand count and yield data were collected for industry tests. A fungicide spray coverage study on sheath blight and false smut consisted of 40 plots of 150 ft^2 to evaluate the importance of canopy coverage using 3 and 10 gallons per acre (GPA) carrier water volumes to mix the fungicides.

The straighthead nursery was set up with the application of two rates of MSMA herbicide prior to planting. Thirty-nine commercial varieties were hand-planted along with five checks to establish 976 plots across 4 bays. At the hard-dough growth stage, primary and secondary tillers were visually compared with checks for their tolerance to straighthead, and ratings were collected using the 0 to 9 scale, where 0 is no symptom of straighthead and 9 severe symptoms of both primary and secondary tillers. In breeder's fields, over 540 plots containing advanced and aromatic breeding lines were assessed for the major rice diseases that occur in Arkansas under natural conditions.

Results and Discussion

Of the 913 experimental lines tested for leaf blast in the greenhouse with five individual races of the pathogen, several were rated as disease resistant/tolerant (Table 1).

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). The use of relatively "slow" growing isolates of *R. solani* continued to meet the objectives for sheath blight screening since more than 50% of the entries were classified as susceptible. Based on a subset of 69 entries from other ARPT and URRN tests, about 70% of lines showed a similar sheath blight rating regardless of the *R. solani* type used (Table 3 and Fig. 1). By combining the results of both inoculum types over at least two years, 18 entries were consistently tolerant to sheath blight, thus making them useful to the breeding program as potential sources of disease tolerance.

The breeding pathology technical support group aided in the successful applied research of the extension rice pathology program. Activities were completed for all funded applied research and other testing, starting from inoculum production in the laboratory to harvest.

Practical Applications

The rice breeding pathology technical support group provides disease data to the breeding program to eliminate 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 providing assistance in applied research and promoting practical information to benefit rice producers. In general, the technical support group is vigorously supporting the breeder and extension rice pathology programs to improve rice production for Arkansas growers.

Acknowledgments

The authors gratefully acknowledge the cooperation of the Arkansas rice producers and the support of the Arkansas Rice Research and Promotion Board through their continued interest and funding. Thanks also go to other University of Arkansas System Division of Agriculture Research Stations located throughout Arkansas for their continued support.

Literature Cited

Kelsey, C.D., S.B. Belmar, K.A.K. Moldenhauer, and Y.A. Wamishe. 2016. Rice Breeding and Pathology Technical Support. *In*: R.J. Norman and K.A.K Moldenhauer (eds.). B.R. Wells Arkansas Rice Research Studies 2015. Arkansas Agricultural Experiment Station Research Series 634:103-109. Fayetteville.

Table 1. The number of entries rated tolerant[a] against 5 common races of rice blast pathogen (*Magnaportha grisea*) in the 2021 greenhouse leaf blast test at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center, Stuttgart.

Test	Total Entries	IE1K	IC17	IB17	IB49	IB1
URRN	220	91	133	95	147	104
ARPT	50	21	16	25	10	16
Aromatic AYT	42	21	11	8	17	24
Aromatic SIT[b]	72	34	23	34	11	36
Advance	59	22	11	9	5	9
IMI-Advance	63	14	23	16	14	21
IMI-SIT[b]	193	66	60	80	57	97
			Combined individual races "bulk" tested			
SIT-A[b]	90	27		24		
SIT-B[b]	124	19		34		

[a] Disease severity rating of 4 (small diamond-shaped lesion with ashy center) or less on a 0 (healthy tissue) to 9 (elongated necrotic tissue) scale.
[b] SIT previously reported as preliminary entries.
URRN = Uniform Regional Rice Nursery; ARPT = Arkansas Rice Performance Trials; AYT = Arkansas Yield Trials; SIT = Stuttgart Initial Test; IMI = Imidazolinone.

Table 2. The number of entries rated sheath blight tolerant in 2021 field nursery at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center, Stuttgart.

Test	Total entries screened	Entries tolerant to "slow" growing isolate[a]
ARPT	48	16
URRN	240	52
Aromatics[b]	109	42
SIT	204	119
IMI-Advance	63	14
IMI-SIT	194	54
Advance	54	26

[a] Rating scale of 0 (no disease) to 9 (severe disease) was used. A "6" represents disease progression of approximately 60% up the plant and is considered tolerant for average scores of 6.3 or less.
[b] Collectively includes Arkansas Yield Trial and Stuttgart Initial Trial varieties.
ARPT = Arkansas Rice Performance Trials; URRN = Uniform Regional Rice Nursery; SIT = Stuttgart Initial Test; IMI = Imidazolinone.

Table 3. Sheath blight score[a] on 69 entries using "slow" and "fast" growing *R. solani* isolates in 2021 field nursery at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center, Stuttgart.

Slow/fast growing isolate score	Count	Percent
Tolerant/tolerant	18	26.1
Susceptible/susceptible	30	43.5
Tolerant/susceptible	19	27.5
Susceptible/tolerant	2	2.9

[a] Visual numeric score for sheath blight rating converted to tolerant if 6 and less, otherwise, susceptible.

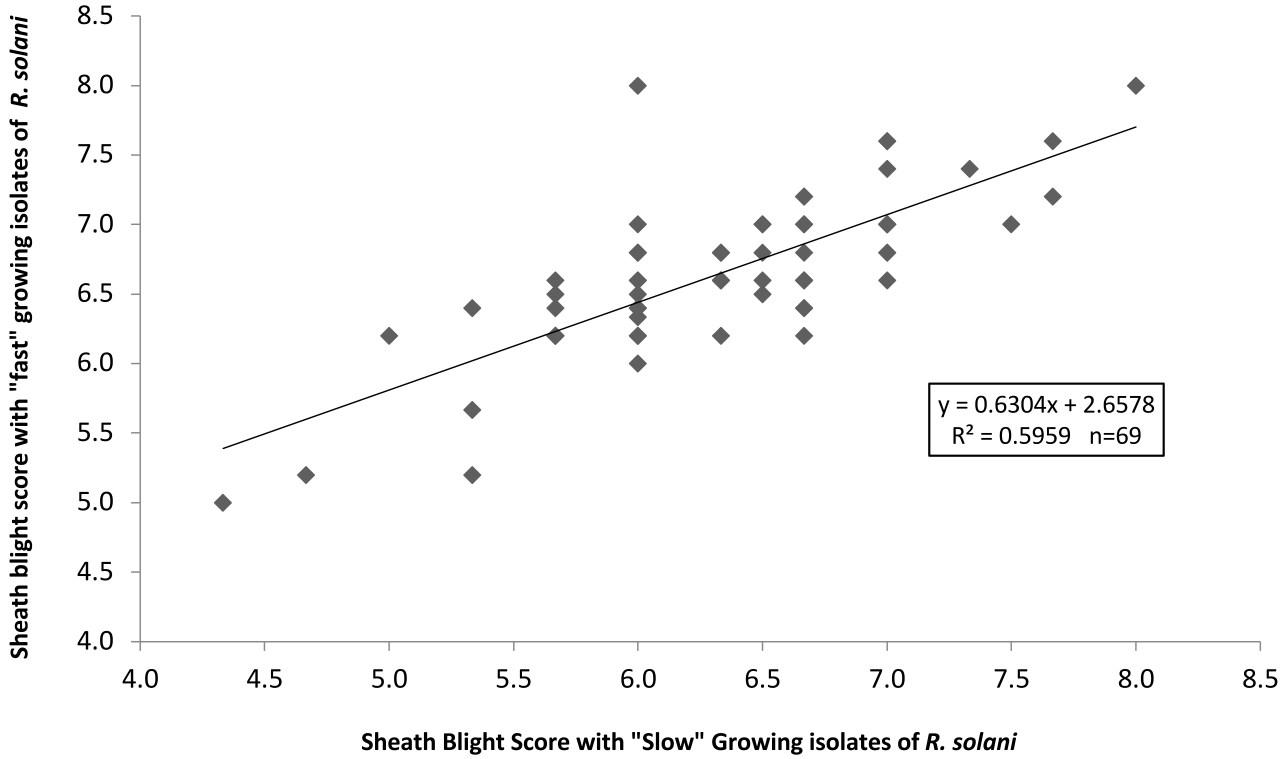

Fig. 1. Comparison of sheath blight ratings using “slow” and “fast” growing fungal isolates of *R. solani* for the same rice entry. Note: Some data points represent more than one observation.

Investigating the Genetic Basis of Resistance to Bacterial Panicle Blight of Rice at High Night Temperatures

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Abstract

The disease Bacterial Panicle Blight (BPB), caused by the bacterium *Burkholderia glumae,* has affected rice production worldwide. Bacterial panicle blight has been prevalent in rice-growing areas of the world with high nighttime temperatures. Similarly, in Arkansas and other rice-growing states of the mid-South, outbreaks of BPB have occurred in years with unusually high temperatures, especially at night, suggesting that night temperatures are important for disease development. With the continuous rise in global temperatures, it has been suggested that BPB will be more devastating in the years to come. In order to understand the effect of high night temperatures on BPB, we previously screened 20 rice accessions from the USDA mini-core collection against *B. glumae* infection at low and high night temperatures and uncovered temperature-dependent and temperature-independent accessions. This work used quantitative reverse transcription polymerase chain reaction (RT-PCR) to evaluate gene expression profiles between a moderately resistant accession and a susceptible accession. The results from this work will enable further understanding of the genetic basis of resistance to BPB under high night temperatures.

Introduction

The disease Bacterial Panicle Blight (BPB) caused by *Burkholderia glumae* has affected rice production worldwide, especially when combined with high night temperatures during the growing season (Nandakumar et al., 2009; Wamishe et al., 2015; Shew et al., 2019; Zhou, 2019; Echeverri-Rico et al., 2021). These findings highlight an interplay between BPB and high night temperatures that has led to the suggestion that this disease can become more prevalent with climate change (Ham et al., 2011), yet the interplay between BPB and high night temperatures has not been systematically investigated.

We previously screened 20 rice accessions from the USDA mini-core collection against *B. glumae* under low (72 °F) and high (82 °F) night temperatures and found temperature-dependent and temperature-independent responses, ranging from enhanced susceptibility to enhanced resistance at high night temperatures (Ortega et al., 2019). Among those accessions, accession GSOR310131 was found to be moderately resistant to *B. glumae* at both night temperatures, whereas accession GSOR311383 was found to be susceptible to *B. glumae* at both temperatures. To further understand the genetic basis of BPB resistance at high night temperature, this work identified genes from the literature and used comparative quantitative RT-PCR (qRT-PCR) to evaluate their expression in GSOR310131 and in GSOR311383. The results revealed that most of the genes had higher levels of expression in the susceptible accession at low night temperature, and only one gene, *Os05g28740*, encoding a universal stress protein, is upregulated in the moderately resistant accession at high night temperature. The implications of these results are currently unknown; more research is needed to dissect the function of these genes in the BPB/high night temperature interplay.

Procedures

Plant Material

Accessions GSOR310131 and GSOR311383 were obtained from the Agricultural Research Service-United States Department of Agriculture (Dale Bumpers National Rice Research Center, Stuttgart, Arkansas). Rice seeds were de-husked, surface-sterilized, and grown in soil as previously described (Ortega et al., 2020). Plants were maintained in a greenhouse set up at 86 °F day/ 72 °F night until using them for experiments. Flowering plants at the R4-R5 stage were sprayed with a suspension of *B. glumae* at OD_{600} = 1.0 (1×10^8 CFU/ml) in 0.01% Tween 20 or mock-treated with water containing 0.01% Tween 20. Following treatment, plants were transferred to a greenhouse set up for low night temperature conditions (86 °F day/ 72 °F night) or high night temperature conditions (86 °F day/ 82 °F night).

Gene Expression Analysis

Flag leaves from *B. glumae*- or water-treated plants were harvested for RNA extraction followed by cDNA synthesis and qRT-PCR, and expression of the gene of interest was normalized to the expression of the housekeeping gene (Ortega et al., 2019).

Results and Discussion

To start dissecting the genetic components associated with BPB resistance at high night temperatures, we conducted qRT-PCR on two temperature-independent accessions that showed contrasting responses to *B. glumae* inoculation: accession GSOR 311383 showed enhanced susceptibility at both temperature regimes, whereas accession GSOR 310131 showed enhanced resistance at both temperature regimes. Mock and pathogen-treated plants from both accessions and temperature regimes were used for qRT-PCR

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gene expression analyses using eight genes that were either previously identified as being differentially regulated in moderately resistant and susceptible cultivars after inoculation with *B.glumae* (Magbanua et al., 2014) or known to be differentially regulated in response to several abiotic and biotic stresses (Narsai et al., 2013). Those genes are *Os05g28740*, encoding a universal stress response protein; *Os06g07030*, encoding an *AP2*-type transcription factor; *Os02g02840*, encoding a RacB GTPase; *Os07g159500*, the ortholog of AtNHR2B (Singh et al., 2018); *Os11g12300* and *Os11g12330*, encoding proteins predicted to participate in defense responses; *Os08g25050*, encoding the transposon-like element *PIF1;* and *Os11g12040*, encoding an ortholog of the Arabidopsis resistance protein RPM1 (Boyes et al., 1998).

Quantitative RT-PCR revealed that *Os05g28740* showed low levels of expression at low temperature with a slightly but significantly higher level of expression in the accession with enhanced resistance (GSOR 310131). In addition, while the levels of expression did not change for the susceptible accession (GSOR 311383) at high night temperatures, they increased by 3-fold in the resistant accession (GSOR 310131), indicating that this gene contributes to the resistant responses to *B. glumae* and high temperature. Gene *Os06g07030* was expressed at low levels at low temperature and at higher levels at high temperature, but this pattern of expression did not differ between the susceptible and the resistant accession. In contrast to the expression of *Os05g28740* and *Os06g07030* that showed induction at high temperatures, *Os02g02840* showed higher levels of expression at low temperatures and lower levels of expression at high temperatures, and a significant difference in expression between accessions was only observed at low temperatures, with higher levels in the susceptible accession. In the case of *Os07g159500*, its levels of expression were higher at high temperatures in both accessions, but the susceptible showed significantly higher levels of expression in comparison with the accession that showed enhanced resistance. The expression of *Os11g12330*, *Os08g25050*, *Os11g12040,* and *Os11g12300* showed higher levels of expression in the susceptible accession, especially at low night temperatures. Intriguingly, no transcript was detected for *Os11g12040* and *Os11g12300* (Fig. 1).

While these results highlight unique patterns of gene expression between the moderately resistant and susceptible accessions, larger-scale transcriptomics studies are needed to further identify genes responsible for resistant responses to *B. glumae* under high night temperatures.

Practical Applications

Bacterial Panicle Blight has the potential to be devastating when combined with high night temperatures. Thus, understanding the effect of high night temperatures on BPB is of critical importance to advance the development of rice cultivars resilient to BPB under conditions of high night temperatures. The results from this work started to unravel the complex BPB-high night temperature interplay, a more comprehensive picture is needed to gain better insight into genes and pathways underlying these processes that, in turn, can inform the development of climate change-resilient and BPB resistant varieties.

Acknowledgments

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Literature Cited

Boyes, D.C., J. Nam, and J.L. Dangl. 1998. The *Arabidopsis thaliana RPM1* disease resistance gene product is a peripheral plasma membrane protein that is degraded coincident with the hypersensitive response. Proc Natl Acad Sci U S A 95:15849-15854.

Echeverri-Rico, J., E. Petro, P.A. Fory, G.M. Mosquera, J.M. Lang, J.E. Leach, J.D. Lobaton, G. Garces, R. Perafan, N. Amezquita, S. Toro, B. Mora, J.B. Cuasquer, J. Ramirez-Villegas, M.C. Rebolledo, E.A. and Torres. 2021. Understanding the complexity of disease-climate interactions for rice bacterial panicle blight under tropical conditions. PLoS One 16:e02 52061.

Ham, J.H., R.A. Melanson, and M.C. Rush. 2011. *Burkholderia glumae*: next major pathogen of rice? Mol Plant Pathol. 12:329-339.

Magbanua, Z.V., M. Arick II, T. Buza, C.Y. Hsu, K.C. Showmaker, P. Chouvarine, P. Deng, D.G. Peterson, and S. Lu. 2014. Transcriptomic dissection of the rice-*Burkholderia glumae* interaction. BMC genomics 15:755.

Nandakumar, R., A.K.M. Shahjahan, X.L. Yuan, D.E. Groth, C.A. Clark, R.D. Cartwright, and M.C. Rush. 2009. *Burkholderia glumae* and B. gladioli cause bacterial panicle blight in rice in the Southern United States. Plant Dis 93:896-905.

Narsai, R., C. Wang, J. Chen, J. Wu, H. Shou, and J. Whelan. 2013. Antagonistic, overlapping and distinct responses to biotic stress in rice (*Oryza sativa*) and interactions with abiotic stress. BMC Genomics 14:93.

Ortega, L., K.A. Walker, C. Patrick, Y. Wamishe, A. Rojas, and C. Rojas. 2020. Harnessing *Pseudomonas protegens* to control Bacterial Panicle Blight of Rice. Phytopathology 111 (5):772-778.

Shew, A.M., A. Durand-Morat, L.L. Nalley, X.G. Zhou, C. Rojas, G. and Thoma. 2019. Warming increases Bacterial Panicle Blight (*Burkholderia glumae*) occurrences and impacts on USA rice production. PLoS One 14:e0219199.

Singh, R., S. Lee, L. Ortega, V.S. Ramu, M. Senthil-Kumar, E.B. Blancaflor, C.M. Rojas, and K.S. Mysore. 2018. Two Chloroplast-Localized Proteins: AtNHR2A and AtNHR2B, Contribute to Callose Deposition During Nonhost Disease Resistance in Arabidopsis. Mol Plant Microbe Interact 31:1280-1290.

Wamishe, Y., C. Kelsey, S. Belmar, T. Gebremariam, and D. McCarty. (2015). Bacterial Panicle Blight of Rice in Arkansas. University of Arkansas System Division of Agriculture. Research and Extension.FSA7580

Zhou, X.G. 2019. Sustainable Strategies for Managing Bacterial Panicle Blight of Rice. in: Protecting Rice Grains in the Post-Genomics Era, IntechOpen.

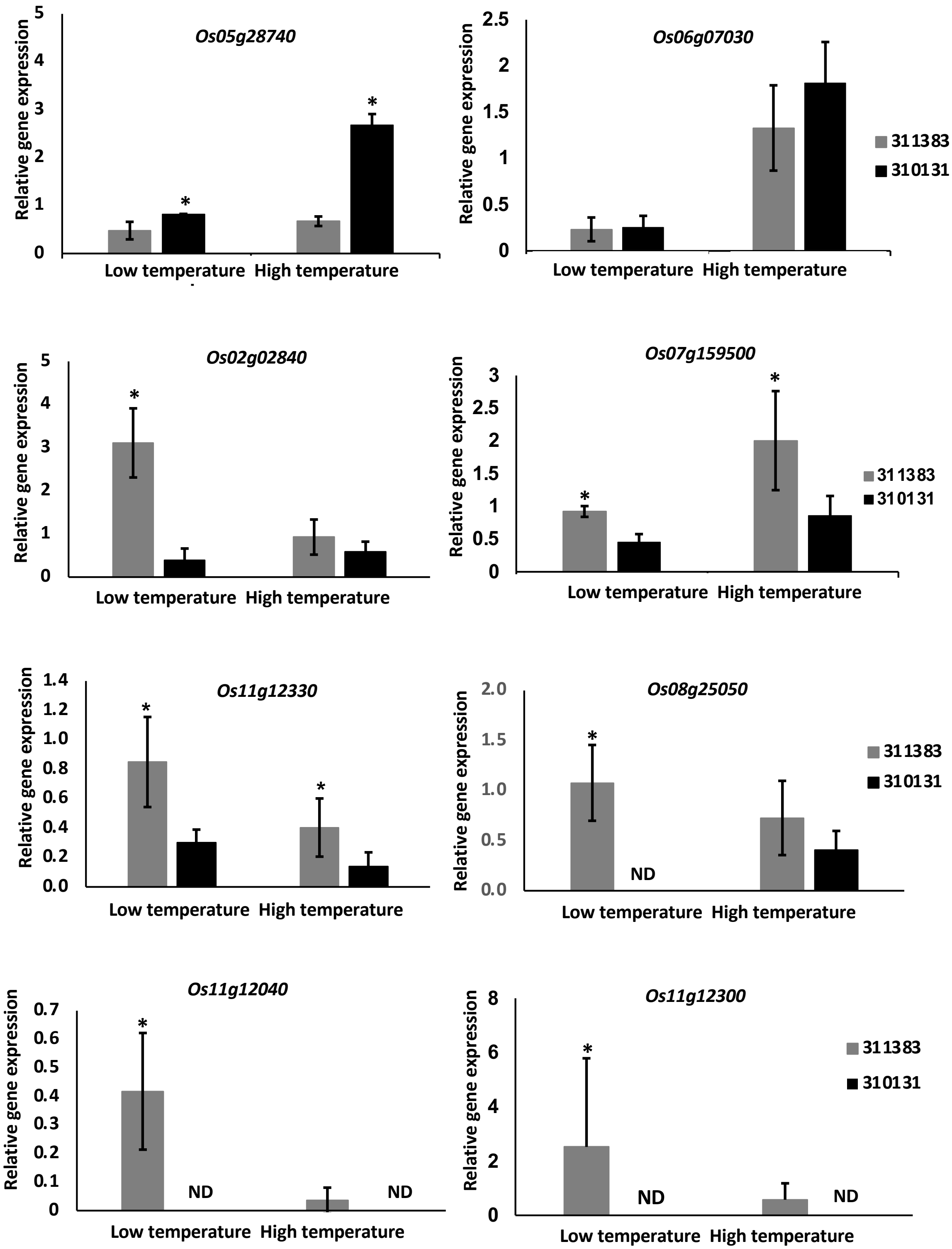

Fig. 1. Comparative gene expression analysis between bacterial panicle blight (BPB)-moderately resistant and BPB-susceptible accessions under low and high night temperatures. Quantitative RT-PCR was used to evaluate the expression of the target genes *Os05g28740*, *Os06g07030*, *Os02g02840*, *Os07g159500*, *Os11g12330*, *Os08g25050*, *Os11g12040,* and *Os11g12300* in the moderately resistant accession GSOR310131 and the susceptible accession GSOR311383. Gene expression of the target gene in *B. glumae*-inoculated samples was normalized to the expression of the glyceraldehyde phosphate dehydrogenase (GAPDH) gene and with the mock-treated samples.

Evaluating the Effectiveness of *Pseudomonas protegens* PBL3 and *Burkholderia cepacia* PBL18 Against Fungal Pathogens

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Abstract

Fungal and bacterial diseases significantly affect rice production worldwide. Effective control of those diseases can be achieved by planting resistant cultivars or applying chemical control when available. Developing broad spectrum resistant cultivars is time-consuming, and the use of chemical control is expensive, which can also pose serious effects on the environment and can become ineffective as pathogens can develop resistance against those chemicals. In the absence of broad-spectrum resistant cultivars or effective chemical control, biological control, using living organisms or molecules derived from them, is an effective and environmentally friendly strategy to eliminate or reduce populations of pathogens. We previously identified two environmental bacteria, *Pseudomonas protegens* PBL3 and *Burkholderia cepacia* PBL18, with biological control activities against bacterial and fungal pathogens of rice under laboratory conditions. We also found that the secreted fraction of *P. protegens* PBL3, lacking the living bacteria, was also effective against *B. glumae*, suggesting that this fraction could be further used in the development of biologically based products lacking the producer organism. In this work, we evaluated the effectiveness of the secreted fraction of *B. cepacia* PBL18 against fungal pathogens and also tested the effectiveness of both *P. protegens* PBL3 and *B. cepacia* PBL18 in protecting seeds against fungal infections.

Introduction

Several fungal and bacterial pathogens of rice cause significant yield loss and, therefore, represent a detrimental economic impact for the state of Arkansas. Those pathogens include *Rhizoctonia solani*, *Fusarium* sp., and *Burkholderia glumae* (Wamishe et al., 2013). Previously, we identified that the environmental bacterial strains *Pseudomonas protegens* PBL3 and *Burkholderia cepacia* PBL18 had antagonistic activity against *B. glumae*, the causal agent of Bacterial Panicle Blight of rice (Ortega et al., 2020b). These two strains reduced the growth of *B.glumae* in vitro and in planta, making them valuable as biological control agents. Interestingly, both strains also reduced the growth of fungal and oomycete pathogens such as *Magnaporthe grisea, Rhizoctonia solani*, *Pythium sylvaticum*, *P. ultimum,* and *P. irregulare*, although the growth inhibition effects on fungal pathogens were stronger with *B. cepacia* PBL18 than with *P. protegens* PBL3 (Ortega et al., 2020a).

In the process of characterizing the biological control activity of *P. protegens* PBL3 against *B. glumae*, we also found that this antagonistic activity of *P. protegens* PBL3 was associated with its secreted fraction, suggesting that this secreted fraction could be harnessed for the development of cell-free biopesticides, that are viewed as more effective because they provide more consistent results than when using living microorganisms (Glare et al., 2016; Marrone, 2019). In this work, we showed that the cell-free secreted fraction from *B. cepacia* PBL18 reduced the growth of *R. solani* under laboratory conditions and that both *P. protegens* PBL3 and *B. cepacia* PBL18 overcome the effects of *F. graminearum* affecting seed germination.

Procedures

Preparation of Cell-Free Secreted Fractions from *B. cepacia* PBL18

A single colony of *B.cepacia* PBL18 was grown in 5 ml of Luria Bertani (LB) broth at 82 °F for 24 h, subcultured into 250 ml of LB broth, and grown with aeration at 82 °F for 24 h. The *B. cepacia* PBL18 culture was centrifuged for 10 minutes at 10,000 rpm, and the supernatant containing bacterial secretions was collected and lyophilized for 24 h. The lyophilized cell-free secreted fraction from *P. protegens* PBL3 was resuspended in sterile water at 0.05g/mL and 0.1 g/ml.

Preparation of *Rhizoctonia solani* Inoculum for Growth Inhibition Assays

Rhizoctonia solani was grown on soft PDA agar plates. Plates were incubated for 4 days to allow the fungus to fully colonize plates. After colonization, 6–8 plugs of colonized media were transferred into a 10-mL syringe. Fungal plugs were passed three times through a 20-gauge needle and collected into a 15-mL tube and further homogenized by vortexing. Potato Dextrose Broth (PDB) at quarter strength, alone or in combination with *B. cepacia* PBL18 secreted fraction at 0.05g/ml, or 0.1g/ml, was aliquoted into a 48-well plate (6 rows × 8 columns). Rows 1 and 2 received 200µL of PDB, rows 3 and 4 received 200 µL of PDB amended with *B. cepacia* PBL18 secreted fraction (0.05g/mL), and rows 5 and 6 received 200 µL of PDB amened with *B. cepacia* PBL18 secreted fraction (0.1g/mL). Fifty microliters of homogenized *R. solani* were added to rows 2–8. Row 1 was used as blank. Plates

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were sealed with a breathable film and incubated at 75 ºF for 24 h. The *R. solani* growth was evaluated by measuring optical density at 600 nm (OD_{600}), minus blank measurement.

Preparation of Bacterial Inoculum for Seed Treament. The *P. protegens* PBL3 and *B. cepacia* PBL18 were streaked on King's B (KB) agar and grown at 82 °F for 48 h. A single colony of each strain was transferred to 5 mL of KB media and grown at 82 °F for 24 h with aeration. Grown cultures were centrifuged at 6,000 rpm for 10 minutes. After centrifugation, the supernatant was discarded, and the pellet was resuspended and washed in 750 µL of 0.5× Phosphate Buffered Saline (PBS). The optical density (OD_{600}) of bacterial suspensions was measured in a HT Microplate Reader (Bio-Tek Synergy) and adjusted to a final concentration of 0.02.

Seed Treatment Application. Fifty seeds from the rice cultivar Diamond were treated with a solution containing 1 mL of bacterial suspensions and 1 mL of 1% carboxymethylcellulose (CMC) as a binding agent. Untreated seeds consisted of seeds mixed with 1% CMC alone. Bacteria-treated and untreated control seeds were shaken gently for 30 seconds and left undisturbed for additional 20 minutes. Seeds were air-dried on sterile paper towels for 5 minutes before use.

Seed Plate Assay Experiment Set Up. Isolates of *R. solani* AG 1-IA, AG 4, AG 7, and *F. graminearum* Fg_4 were grown on solid PDA media for 5–7 days at room temperature. Eight grams of autoclaved high-grade vermiculite (Palmetto Vermiculite Co., SC) per plate were evenly spread on top of the fully colonized PDA culture. Treated seeds (15 per plate) and untreated controls (2 per plate) were placed on top of the thin layer of sterile vermiculite. A batch of bacteria-treated seeds was further incubated with pathogenic fungi; another batch was not incubated with fungi. Similarly, a batch of seeds untreated with bacteria was incubated with pathogenic fungi; whereas another batch of seeds untreated with bacteria was also left without fungi. Five replicates per treatment per pathogen were used. The plates were covered using aluminum foil and kept at room temperature for one week. Percent germination was recorded after one week of incubation at room temperature. Germination was taken using the Association of Official Seed Analyst (AOSA) germination protocol, in which a seedling is considered healthy when 50% of its cotyledonary tissue remains attached or free of decay.

Results and Discussion

We previously found that the secreted fraction of the *P. protegens* PBL3 contains molecules with antimicrobial activities against *Burkholderia glumae* and fungal pathogens, and utilizing cell-free secreted fractions is desirable as a biological control strategy against plant diseases. Our preliminary data showing that *B. cepacia* PBL18 is effective in controlling fungal diseases prompted us to investigate whether the antimicrobial activity was also found in the *B. cepacia* PBL18 secreted fraction. For that purpose, we isolated the *B. cepacia* PBL18 secreted fraction and used it to amend the culture media in which *R. solani* AG 1-IA was grown. The results show that the growth of *R. solani* AG 1-IA without *B. cepacia* PBL18 cell-free secreted fraction ranged from OD_{600} of 0.05–0.12. Amending the media with the *B. cepacia* PBL18 cell-free secreted fraction at a low concentration (0.05g/ml) showed a similar growth range to the growth without it and ranged from OD_{600} of 0.075–0.12. Interestingly, the growth of *R. solani* AG 1-IA in media supplemented with the *B. cepacia* PBL18 cell-free secreted fraction at a higher concentration (0.1g/ml) showed a range from no growth to an OD_{600} of ~0.075 (Fig. 1).

In addition to using the cell-free secreted fraction, we also pre-treated seeds with the living bacteria (*P. protegens* PBL3 and *B. cepacia* PBL18) and then inoculated them with *F. graminearum*, *R. solani* AG1-IA, *R. solani* AG4, and *R. solani* AG7 to evaluate seed germination and compare with germination of seeds that were not pre-treated with bacteria but inoculated with the fungal pathogens (Fig. 2). The results showed that seeds that were not pre-treated with *B. cepacia* PBL18 but inoculated with *F. graminearum* showed ~20% germination, whereas seeds that were pre-treated with *B. cepacia* PBL18 and further inoculated with *F. graminearum* showed enhanced germination of 58%.

Inoculation with *R. solani* AG1-IA and *R. solani* AG7 did not appear to significantly affect seed germination, and therefore the effect of *B. cepacia* PBL18 is not very clear. However, when seeds were inoculated with *R. solani* AG4, they showed ~55% germination, and that germination was enhanced to ~75% with pre-treatment with *B. cepacia* PBL18.

The effect of pre-treatment with *P. protegens* PBL3 was only observed with *F. graminearum*, as *F. graminearum* inoculated seeds had ~20% germination but pre-treatment with *P. protegens* PBL3 enhanced germination to more than 50%.

Altogether, these results demonstrate that both *B. cepacia* PBL18 and *P. protegens* PBL3 protect seeds against *F. graminearum* resulting in enhanced seed germination.

Practical Applications

This work will pave the way toward deploying *P. protegens* and *B. cepacia* as sources to control Bacterial Panicle Blight of rice and other important rice diseases caused by fungal and oomycete pathogens. Controlling these diseases will reduce their economic impact while providing environmentally friendly options that are also accepted by consumers.

Acknowledgments

This research was supported by the University of Arkansas System Division of Agriculture, the Arkansas Rice Checkoff Program administered by the Arkansas Rice Research and Promotion Board, and the University of Arkansas Chancellor's Commercialization Fund.

Literature Cited

Fory, P.A., L. Triplett, C. Ballen, J.F. Abello, J. Duitama, M.G. Glare, T.R., Gwynn, R.L., and Moran-Diez, M.E. 2016. Development of Biopesticides and Future Opportunities. Methods Mol. Biol. 1477:211-221.

Marrone, P.G. 2019. Pesticidal natural products - status and future potential. Pest Manag. Sci. 75:2325-2340.

Ortega, L., Delgado, L., Rojas, A., and Rojas, C.M. 2020a. Control of Rice Diseases in Arkansas by Using Antagonistic Bacteria and Products Derived from Them. *In*: J. Hardke, X. Sha, and N. Bateman (eds.) B.R. Wells Arkansas Rice Research Studies 2020. Arkansas Agricultural Experiment Station Research Series 676:78-80. Fayetteville.

Ortega, L., Walker, K.A., Patrick, C., Wamishe, Y., Rojas, A., and Rojas, C.M. 2020b. Harnessing *Pseudomonas protegens* to Control Bacterial Panicle Blight of Rice. Phytopathology 110:1657-1667.

Wamishe, Y., Cartwright, R.D., and Lee, F. 2013. Management of rice diseases. *In*: Arkansas Rice Production Handbook, J.T. Hardke, ed. University of Arkansas System Division of Agriculture Cooperative Extension Service, Little Rock, Ark.

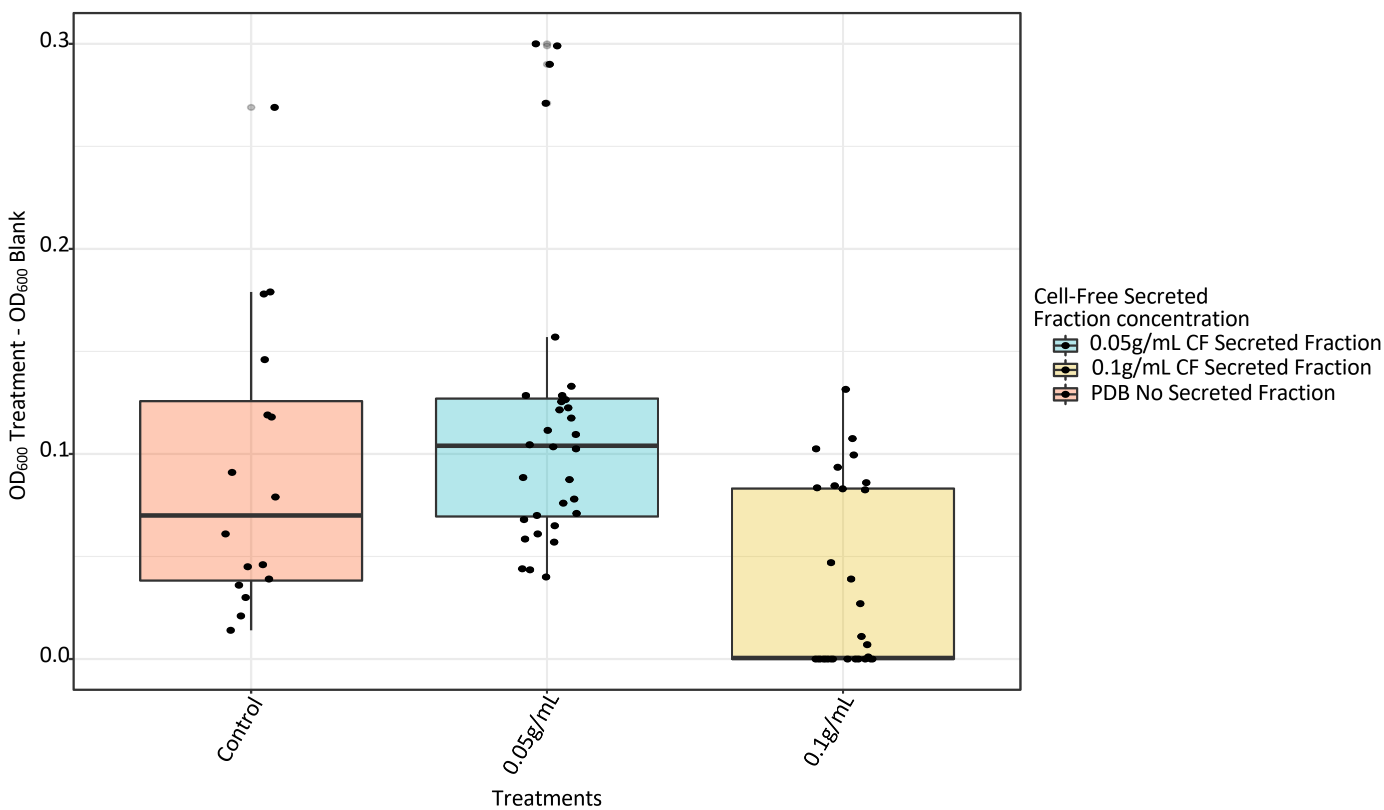

Fig. 1. Evaluation of the effect of *Burkholderia cepacia* PBL18 cell-free bacterial extracts on *Rhizoctonia solani* AG 1-IA growth. *R. solani* AG 1-IA was grown in 48-well plates containing Potato Dextrose Broth (PDB) quarter-strength, or PDB supplemented with *P. protegens* PBL3 extracts at 0.05 g/mL and 0.1 g/mL. *R. solani* AG 1-IA growth was evaluated by measuring optical density at 600nm (OD_{600}). Four replicates per treatment were evaluated.

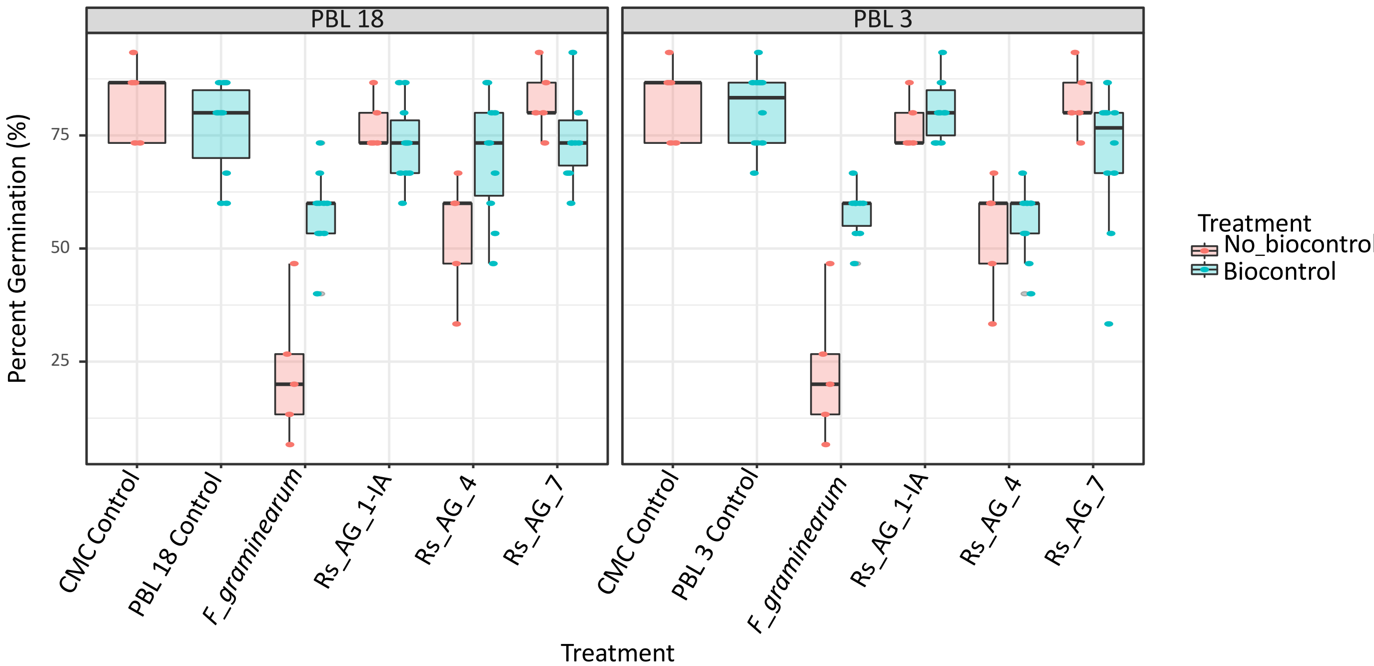

Fig. 2. Rice seeds pre-treated with *Burkholderia cepacia* PBL18 (left) or *Pseudomonas protegens* PBL3 (right) are protected from *Fusarium graminearum*. Rice seeds from cultivar Diamond were pre-treated with live bacterial strains at 10^6 CFUs/mL mixed with an equal volume of 1% dissolved carboxymethylcellulose (CMC) as seed binding treatment. Pre-treated seeds were further inoculated with *F. graminearum* or *Rhizoctonia solani* (Rs AG1-IA, Rs AG4, and Rs AG7). Seed germination was evaluated after 7 days and compared with non- pre-treated seeds (Carboxymethyl cellulose, CMC, control).

Evaluation of Contemporary Rice to Straighthead

Y. Wamishe,[1] J. Hardke,[2] S. Belmar,[1] and C. Kelsey[1]

Abstract

Flooded water from considerable acreage of rice fields is drained every year to manage straighthead, incurring additional costs to rice production. The major objectives of this study were to provide growers with updated information on the susceptibility of the new rice varieties and hybrids regarding their reaction to straighthead, to re-evaluate older varieties still in production, to assess the susceptibility of advanced breeding lines prior to release for commercial production, and to test parental lines from the hybrid rice breeding program for their reaction. This paper reports the procedure and results of the 3rd year field test. However, ratings from the previous two years have been included for users to compare and check for consistency. In 2021, four bays were established at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC), Stuttgart, Arkansas. Each bay had 39 test entries and 5 reference/control entries as hill plots in four replications. Two bays had Monosodium Methanearsonate (MSMA) incorporated in the soil at the rate of 1 gal/ac and the other two bays at 1.5 gal/ac. All were kept flooded up to 4-in. depth starting from the 5-leaf stage through the hard dough stage. Before draining the water, entries were visually examined for straighthead symptoms using the 0 to 9 rating scale. Of 39 entries tested, 16 entries rated from 7 to 9 for susceptibility, 15 rated from 4 to 6, indicating moderate resistance to moderately susceptible response, and the remaining eight entries rated 0 for a high level of tolerance to straighthead and MSMA. When the two rates were compared, the1.5 gal/ac rate showed clear symptoms of straighthead over the 1 gal/ac rate of MSMA.

Introduction

Straighthead in rice (*Oryza sativa*) is one of the oldest reported physiological disorders of unknown cause. Rice florets with straighthead symptoms are commonly sterile, leading to blank rice panicles and, hence, significant decline in grain yield. There may be several factors that contribute to the development of straighthead in different soil types across the rice-growing counties in Arkansas. Unfortunately, once straighthead appears in the problematic rice fields, symptoms appear each time when rice is grown unless cultivars with some levels of resistance are used. In a field planted with susceptible rice, straighthead may develop at some point during the season if the field is not drained and dried to alleviate the problem with adequate soil aeration. In order to reduce the impact on grain yield, the "drain and dry" strategy for the soil should be implemented at appropriate timing, usually before the beginning of reproductive stages of the crop.

The draining and drying management strategy is often difficult when field sizes are too big to adequately drain and timely re-flood. If re-flooding is delayed, the crop may suffer from drought stress. It is worse when water resources are too limited to re-flood the field quickly. Consequently, the use of resistance is cheaper and a more user-friendly option to tackle the yield impact of straighthead. Rice varieties can be R (resistant), MR (moderately resistant), S (susceptible), MS (moderately susceptible), and VS (very susceptible) to straighthead. Although straighthead is known to distress a small percentage of the Arkansas rice acreage, growing S or VS cultivars in fields with a history of it results in an adverse loss of grain yield. To date, most Arkansas acreages with known histories of straighthead are drained and dried before mid-season. If more varieties with resistance are used, then there would be less need to drain and dry the field, hence, reducing the cost and time for rice producers. The main objectives of this study were to provide rice producers with the most current information regarding the susceptibility of relatively newer rice varieties and hybrids to straighthead and to re-evaluate the older varieties that are still in production. Moreover, we included some advanced breeding lines to assess their susceptibility before they are released for commercial production.

Procedures

A field experiment was carried out for the 3rd season in 2021 at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC) near Stuttgart, Ark. to evaluate rice cultivars and advanced breeding lines for resistance or tolerance to straighthead. Plots were established in a field dedicated over a decade ago for evaluating rice germplasm for straighthead. Before planting, the selected area was measured out and burned down with Roundup herbicide. Two rates of Monosodium Methanearsonate (MSMA) at 1 gal and 1.5 gal/ac were applied using a MudMaster calibrated to deliver 20 gal/ac. After application, the treated areas were lightly rototilled to incorporate the arsenate compound into the soil. The following

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day, a total of 39 rice entries were hand planted as hill plots in 4 replications per bay and consisted of 14 conventional cultivars, 10 advanced breeding lines, 5 Rice Tech hybrids, 5 DynaGro inbred lines, and 5 from the University of Arkansas System Division of Agriculture hybrid program. Five additional varieties served as controls or historical reference standards, including Cocodrie and CL151 to represent susceptible, Taggart and RT CLXL745, resistant, and Francis as moderately resistant. The five rice varieties used as controls were planted before and after the first 20 entries and then at the end of the remaining test entries. All entries were planted in 4 adjacent and similar-sized bays totaling 16 replications. All bays were kept flooded starting from the 5-leaf stage. Flood was raised as the entries grew and maintained to at least 4 in. until hard dough stage. A visual rating of a 0 to 9 scale was used where 0 is no symptoms and 9, severe symptoms on primary and secondary tillers.

Results and Discussion

The susceptible control entries (CL151 and Cocodrie) showed high-level straighthead symptoms as either 8 or 9. The moderately resistant control entries (Taggart and Francis) were rated as either 5 or 6, respectively. The resistant control, RT CL745, rated zero (Table 1). Of 39 entries tested, 16 entries rated from 7 to 9 indicating susceptibility, 15 rated from 4 to 6 indicating moderate resistance to moderately susceptible response, and the remaining 8 entries rated 0, indicating a high level of tolerance to MSMA (Fig. 1 and Table1). When the two rates of MSMA were compared, the1.5 gal/ac rate showed more pronounced symptoms of straighthead over the 1 gal/ac rate. Although the test was carried out using a 1gal/ac rate MSMA in both 2019 and 2020, it appeared that the 2021 test using the 1.5 gal/ac rate gave more consistent ratings. The authors suggest the use of the latter rate for future straighthead evaluations of rice cultivars. The data shown below in 2021 are from the bays that received the 1.5 gal/ac rate MSMA. The bays that received a 1 gal/ac rate MSMA showed lower ratings, and there were noticeable variations among replications. Among the 39 rice entries tested in 2021, 6 were retests from 2020. Although the test entry sets were different across the three years, there were some that were tested for only a year or two or three years (Wamishe et al., 2020, 2021). The observed rating variability on some entries suggests the need for a repeated evaluation to get an accurate measure of the plant's response to straighthead. In addition to MSMA rate, flood depth, fertilization rate, and weather conditions such as intense sun or rain may play a role in fluctuating the responses of rice cultivars.

Generally, information regarding the response of commercial rice varieties to straighthead is important to rice producers as they make early decisions on varietal selection, water use, and anticipate costs that may be incurred if the drain and dry strategy is chosen.

Practical Applications

Using the "drain and dry" strategy to manage straighthead is difficult in big fields where water is limited and pump capacity is unable to re-flood the field in a relatively short period of time. However, if the information regarding the responses of commercial varieties to straighthead is fully known, planting resistant or moderately resistant varieties is always the best and most user-friendly management strategy to prevent significant losses that may have occurred due to this physiological disorder.

Acknowledgments

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Literature Cited

Wamishe Y., J. Hardke, and T. Gebremariam. (2020). Evaluation of Contemporary Rice to Straighthead, a Physiological Disorder of Unknown Cause. *In*: K.A.K. Moldenhauer, B. Scott, and J. Hardke (eds.) B.R. Wells Arkansas Rice Research Studies 2019. Arkansas Agricultural Experiment Station Research Series 667:87-89. Fayetteville.

Wamishe Y, Hardke J, and Gebremariam T (2021) Evaluation of Contemporary Rice to Straighthead. *In*: J. Hardke, X. Sha, and N. Bateman (eds.) B.R. Wells Arkansas Rice Research Studies 2020. Arkansas Agricultural Experiment Station Research Series 676:86-88. Fayetteville.

Table 1. Reactions of rice cultivars to Straighthead induced by Monosodium Methanearsenate (MSMA) in field tests at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center, Stuttgart, Ark., in 2021.

Rice Lines	Rate 0–9 scale[a]	Rice Lines	Rate 0–9 scale	Rice Lines	Rate 0–9 scale
CL151[b]	**8**	**CL151**	**8**	**CL151**	**8**
Cocodrie	**9**	**Cocodrie**	**9**	**Cocodrie**	**9**
Francis	**6**	**Francis**	**6**	**Francis**	**6**
RTCLXL745	**0**	**RT CLXL745**	**0**	**RTCLXL745**	**0**
Taggart	**5**	**Taggart**	**5**	**Taggart**	**5**
ARoma 17	8	CLL16	7	RU2001125	6
Diamond	7	CLL17	9	RU2001185	6
Jupiter	5	RT 7301	5	11X185	0
Titan	5	RT 7321 FP	7	DG263L	5
CLL15	8	RT 7521 FP	0	20 DGL274	0
Jewel	8	PVL02	6	20 DGL037	4
ProGold1	7	PVL03	7	20 DGL2065	9
ProGold2	8	RU1801238	5	DGM004	0
CLM04	6	RT 7501	0	R20-010	7
RU1901033	6	RU1901129	0	R20-025	7
RT XP753	0	RU1901137	7	R20-034	6
Lynx	5	RU2001121	9	LG20-012	6
RU1801101	6	RU2001129	7	LG20-014	0

[a] Visual rating of a 0 to 9 scale was used where 0 is no symptoms and 9, severe symptoms on primary and secondary tillers.

[b] The five cultivars in bold were used as the control.

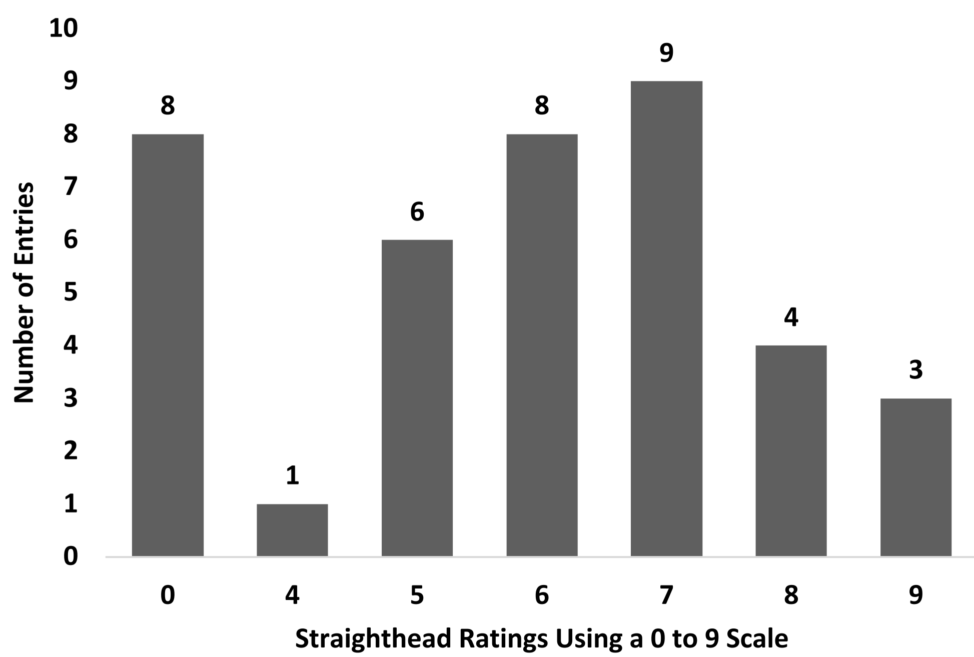

Fig. 1. The number of entries rated 0 to 9 to Monosodium Methanearsenate (MSMA) in field tests at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center, Stuttgart, Ark., in 2021.

Fungicide Application and Coverage for Sheath Blight and False Smut

Y. Wamishe,[1] J. Hardke,[2] S.B. Belmar,[1] C.D. Kelsey,[1] and T.R. Butts[3]

Abstract

Sheath blight caused by *Rhizoctonia solani* AG1-1A is the most prevalent disease in rice fields of Arkansas causing up to 15% grain yield loss. Nearly 57% of rice fields in Arkansas receive at least one fungicide application every year and most of these fungicides are to manage sheath blight. In some commercial rice fields, low application spray volumes used to deliver fungicides to the crop are blamed for the lower efficacy of fungicides used to suppress diseases such as sheath blight and false smut. Field tests for sheath blight suppression were conducted for the 3rd season in 2021 to evaluate two volumes of water (3 and 10 gallons per acre) as a carrier to apply two fungicides (Amistar Top and Quilt Xcel at 15 and 21 fl oz/ac rates, respectively). The sheath blight data analysis showed significant difference in disease suppression and grain yield between the sprayed and unsprayed treatments. However, there was no significant difference in efficacy between Amistar Top and Quilt Xcel in the degree of sheath blight suppression. Sheath blight in unsprayed plots showed most progression throughout the season followed by the plots sprayed with 3 gal/ac. The highest suppression of disease was in plots that received fungicides sprayed using 10 gal/ac of carrier water. In false smut plots, there was no significant differences between the sprayed and unsprayed treatments in the number of galls counted on panicles collected from 8 ft^2 or galls counted from 8.8 lb of harvested seed. Effects of both fungicides and the water volumes used to deliver were not significant in suppressing false smut. Although not significant, the unsprayed plots occasionally had lower diseased panicles or gall counts compared to the sprayed check. When visually compared, panicles of secondary tillers in plots that received fungicides appeared greener and carry more false smut galls than the unsprayed plots. The study on false smut is inconclusive and needs repeated study.

Introduction

Sheath blight in rice is caused by *Rhizoctonia solani* AG1-1A, a soilborne fungus. Sheath blight is a major rice disease accounting for up to 15% grain yield loss in Arkansas. The pathogen has a wide host range including soybean, sorghum, corn, sugarcane, turf grass, and weed hosts such as barnyard grass, crabgrass, and broadleaf signal grass among others. As a result, it has the potential to be found in any field. The fungus survives in soil as mycelia but mostly as a mycelial mass called "sclerotia." The monocyclic infection in flooded rice starts at the waterline. Once infection starts, the disease progresses upward following the height of the crop. The fungus spreads laterally to neighboring plants mostly by leaf-to-leaf contact. Nearly 57% of rice fields in Arkansas receive at least one fungicide application every year and most of the fungicides sprayed are to manage sheath blight in susceptible or moderately susceptible rice varieties. To date, varieties grown in Arkansas are not completely resistant to the disease so monitoring fields for disease is needed.

False smut, also called orange smut, is an emerging rice disease in the United States. The disease can be minor or very conspicuous depending on the variety susceptibility level, season, and favoring conditions. Although the impact of false smut on yield is much lower than sheath blight, in severe situations, it causes chalkiness of grains which leads to reduction of milling and grain quality. Moreover, seed germination can be reduced. Secondary infection can occur by spores that are carried by wind at flowering. The disease commonly affects rice flowers and can destroy the flower pistils.

High nitrogen fertilizer inputs together with rain or high humidity favors false smut disease development. While not offering complete suppression to false smut, propiconazole fungicides were reported to suppress the disease from 50% to 75% (Donald Groth, pers. comm. 2016). Gall size reduction was observed in our previous tests using triazole fungicides of propiconazole and difenoconazole. Generally, higher water volumes to deliver fungicides along with appropriate spray nozzles for medium to coarse droplets contribute to increased coverage and provide the intended level of disease suppression from fungicides. The objective of this experiment was to test two commercially available fungicides at labeled rates with different carrier water volumes to determine levels of suppression to sheath blight and false smut in rice.

Procedures

Field plots were established in 2021 as a 3rd year test for both sheath blight and false smut at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center near Stuttgart, Ark. Rice varieties CL163 and Diamond were selected for their susceptibility to sheath blight and false

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smut, respectively. Each variety was planted in a separate bay beginning with CL163 on 21 April and Diamond on 14 May. Differences in planting dates were depending on favorability of timing for high level of disease pressure. Both varieties were drill-seeded at a maximum recommended seeding rate with an 8-row planter in 30 ft by 5 ft strip plots. The experimental design was a randomized complete block design with 4 replications and 2 factors: two fungicides (Amistar Top and Quilt Xcel) and two carrier water volumes of 3 and 10 gallons per acre.

In both experiments, plots received urea a day prior to permanent flood, at 105 lb N/acre as well as a mid-season application of 45 lb N/acre. In order to introduce false smut spores, galls collected in the previous years were crushed and applied after flood establishment. To artificially establish sheath blight disease, rice plots were inoculated with corn and rice-based *R. solani* AG1-1A inoculum between panicle initiation and panicle differentiation About 200 g of the inoculum was measure out for a plot. The inoculum was hand-broadcasted over each plot followed by a gentle sweep using a PVC pipe approx. 1.3-in. OD (outside diam.) to knock down the inoculum from foliage into the floodwater so the infection could start from the waterline.

Amistar Top and Quilt Xcel were applied 5 days after sheath blight inoculation at 15 and 21 oz/ac, respectively, using two carrier water volumes of 3 and 10 gal/ac. Fungicide application for the false smut plots were at mid-boot stage with the same chemicals and rates. MudMaster™ model MM2013 was used to deliver the fungicides using the two volumes of water with two sets of different nozzle types, sizes, and spray pressures (3 gal/ac, TDXL110005 at 40 PSI; 10 gal/ac, AM11001 at 30 PSI). Sheath blight disease progress data were collected four times during the season i.e., 21, 28, and 45 days after the fungicide application (DAA) and 2 weeks prior to anticipated timing to harvest. The 0 to 9 scale was used to estimate vertical disease progress where 0 is no disease and 9 indicated disease at flag leaf. Horizontal disease spread was estimated using the percentages of plants with sheath blight lesions in an approximately 3-ft length of the middle two rows of each plot. Disease index was calculated by multiplying the vertical disease progress by the horizontal progress. Percent panicles infected with false smut were estimated from an 8 ft^2 area inside each plot of 150 ft^2 along with the number of false smut galls counted from 8.8 lb seeds harvested from each plot. Sheath blight disease indices, false smut disease indicators, and yields were analyzed statistically using PROC GLM procedure of SAS 9.4 (SAS Institute. Inc. Cary N.C.).

To better understand spray dynamics from these applications, droplet size and droplet velocity were determined last year (Wamishe et al., 2021).

Results and Discussion

The sheath blight data analysis from the field test of 2021 showed significant difference in disease suppression and grain yield ($P > 0.05$) between the sprayed and unsprayed plots. However, there was no significant difference between Amistar Top and Quilt Xcel, each having an azoxystrobin equivalent of 12 fl oz/ac rate for sheath blight suppression. Therefore, both fungicides showed similar efficacy level on *Rhizoctonia solani* AG1-1A. Sheath blight in unsprayed control plots showed progression throughout the season followed by the plots with an application rate of 3 gal/ac. The highest suppression of the disease was in plots that received fungicides sprayed using 10 gal/ac of carrier water (Fig. 1).

No significant difference in grain yield was observed between the sprayed plots using 3 gal/ac and the unsprayed plots. However, plots that received either Amistar Top or Quilt Xcel using 10 gal/ac water had significantly lower disease (Fig. 1) and hence higher yield compared to the unsprayed plots or plots with 3 gal/ac water (Fig. 2). The yield data showed similar trends to those of 2019 (Wamishe et al., 2020). In 2020, yield data were not collected due to severe lodging caused by the disease and high-speed wind due to tropical storms (Wamishe et al., 2021). The three-year study supports the need and prominence of adequate coverage to increase fungicide efficacy to suppress sheath blight.

For false smut there was no significant differences between sprayed and unsprayed plots in the percentage of diseased panicles having one or more galls or in the number of galls counted in 8.8 lb (4kg) of harvested seeds. No significant differences were found in the head and total milled rice yield. Although the mean yield in the unsprayed plots appeared lower than means from plots that received fungicides, it did not appear to be due to differences in infection levels (Table 1). Plots sprayed with fungicides were visually greener, particularly the secondary tillers, than the unsprayed plots as the season tapered off. The greener the rice, the more chance for secondary infection to occur and hence, greater gall and diseased panicle counts expected. However, results were far from the expected with yield generally low across the test. Results presented from this study are based on ground spray equipment, nozzles, and application dynamics that may not fully correlate to aerial applications.

Practical Applications

There are times when fungicides may be effectively delivered but diseases may not be suppressed as intended. Such situations incur application costs and grain yield loss from diseases. There are several factors that play roles in reducing efficacies of fungicides. Although development of genetic insensitivities to the fungicides is possible, so far there is no report of fungicide resistance in Arkansas rice. Generally, fungicides protect rice in well managed fields, provided rate, timing, and other application conditions (such as carrier water volume and droplet size) are adequate to provide good foliar coverage.

Acknowledgments

The authors appreciate the funding support from the rice growers of Arkansas administered by the Arkansas Rice Research and Promotion Board and funding from the University of Arkansas System Division of Agriculture.

Literature Cited

Y. Wamishe J. Hardke, T. Gebremariam, S.B. Belmar, C.D. Kelsey, and T. Mulaw. 2020. Evaluation of Fungicide Application and Coverage to Suppress Rice Diseases Using Sheath Blight as a Model. *In*: K.A.K. Moldenhauer, B. Scott, and J. Hardke (eds.). B.R. Wells Arkansas Rice Research Studies 2019. Arkansas Agricultural Experiment Station Research Series 667:90-92. Fayetteville.

Y. Wamishe, J. Hardke, T. Gebremariam, S.B. Belmar, C.D. Kelsey, and T.R. Butts. 2021. Fungicide Application and Coverage for Sheath Blight and False Smut. *In*: J. Hardke, X. Sha, and N. Bateman (eds.). B.R. Wells Arkansas Rice Research Studies 2020. Arkansas Agricultural Experiment Station Research Series 676:81-85. Fayetteville.

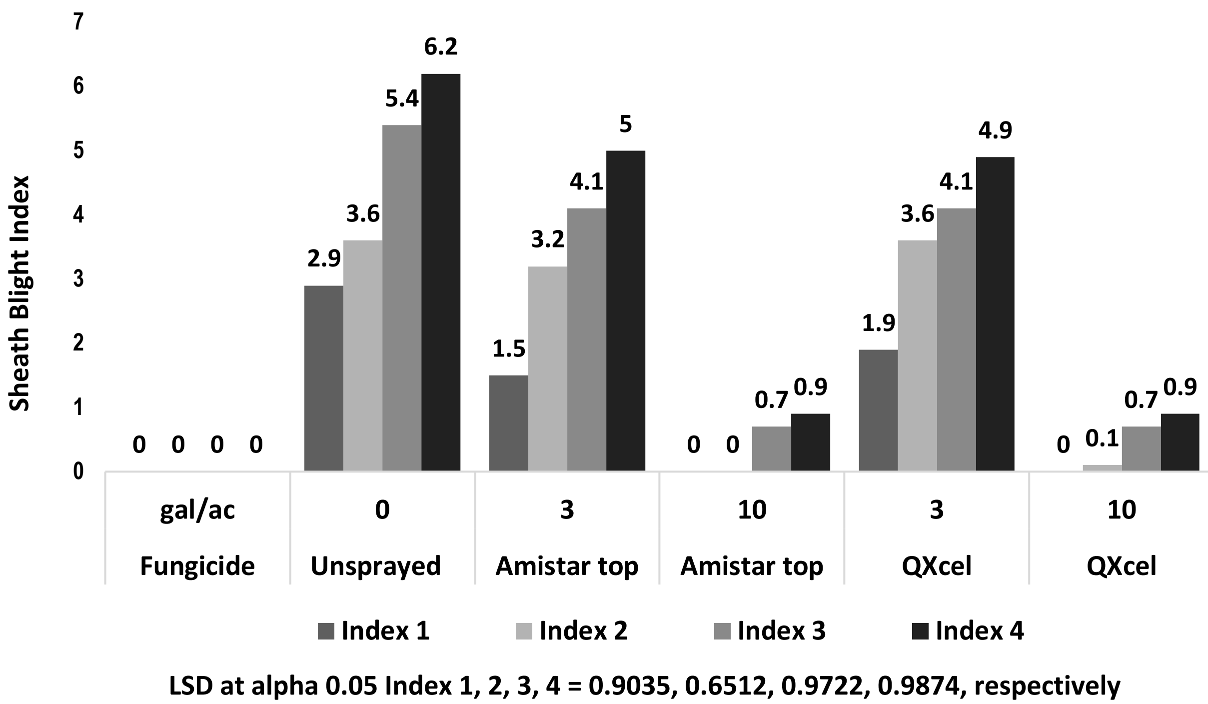

Fig. 1. Efficacy of Amistar Top at 15 fl oz/ac rate and Quilt Xcel at 21 fl oz/ac rate, applied with carrier water volumes of 3 and 10 gal/ac rates to suppress rice sheath blight as calculated with a disease index. Data columns represent the corresponding sheath blight disease progress data collected during the season at 21, 28, and 45 days after the fungicide application and 2 weeks prior to harvest as indicated by the four columns within a treatment.

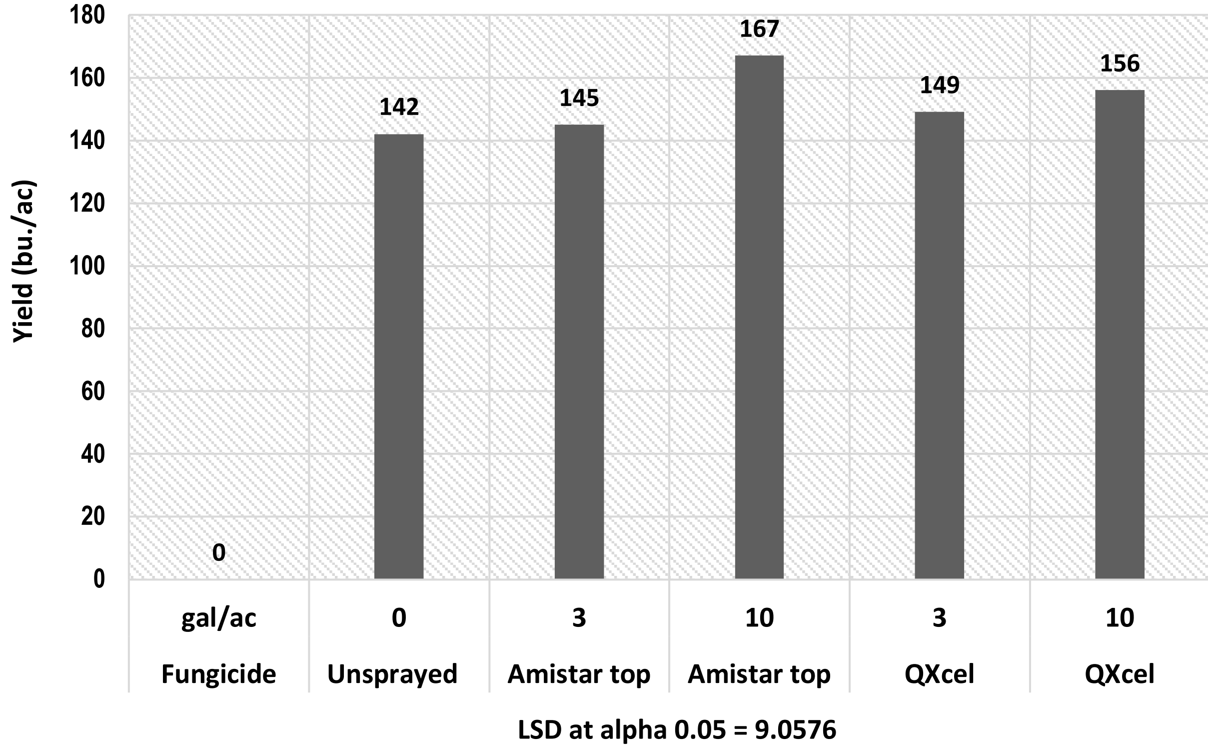

Fig. 2. Efficacy of Amistar Top at 15 fl oz/ac rate and Quilt Xcel at 21 fl oz/ac rate, applied with carrier water volumes of 3 and 10 gal/ac rates to suppress rice sheath blight and increase grain yield.

Table 1. The effect of carrier water volume rate to deliver two fungicides at the recommended rates to reduce false smut and increase grain yield in 2021.

Fungicide	Water Volume	Grain Yield	Panicles	Gall Count	Head Yield	Total Yield
	gal/ac	bu./ac	% sick	in 8.8 lb seed	%	%
Control	Unsprayed	126 a[†]	9	10	58	67
Amistar Top	3	144 b	8	6	58	68
Quilt Xcel	3	132 ab	8	8	59	68
Amistar TOP	10	142 b	13	7	59	68
Quilt Xcel	10	130 ab	8	6	59	68
LSD at 0.05	-	15.5	7.1	4.3	2.4	1.7

[†] Mean values in a column followed by different letters are not significantly different.

Comparing insecticide coated urea to insecticide seed treatments for control of rice water weevil

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Abstract

Grape colaspis and rice water weevil are major pests of rice in Arkansas. The larvae of these pests feed on the root system of the rice plant. Grape colaspis damages rice prior to flood, and rice water weevil feed on rice after permanent flood establishment. The main control strategy for these pests is the use of insecticide seed treatments. For rice water weevil, foliar insecticide applications are also a control option but typically are less consistent than insecticide seed treatments. Insecticide-coated urea has proven to be an effective control option for rice water weevil but needs to be evaluated against currently labeled insecticides. A study was conducted in 2021 at two locations comparing insecticide seed treatments and insecticide-coated urea for control of rice water weevil. Insecticide-coated urea provided some control of rice water weevil and yield increases compared to the untreated control; however, insecticide seed treatments provided more consistent control and yield increases. These studies suggest that insecticide-coated urea could be a control option for rice water weevil, but more work is needed to determine the correct product, rate, and timing for more efficient control.

Introduction

In Arkansas, there are multiple soil pests that feed on rice plants. Of these pests, grape colaspis (*Colaspis brunnea*) and rice water weevil (*Lissorhoptrus oryzophilus*) are the most economically important (Lorenz et al., 2018). Grape colaspis larvae feed on seedling rice, typically causing plant death and stand loss. Rice water weevil adults are attracted to flooded rice and migrate to the field shortly after permanent flood establishment. The adult rice water weevils feed on rice leaves, leaving linear feeding scars. This feeding is superficial and causes no yield loss; however, the larvae of rice water weevils can cause tremendous yield loss at high densities. Rice water weevil larvae feed on the roots of rice plants, causing root pruning and in severe cases, plant death (Lorenz et al., 2018).

Insecticide seed treatments and foliar insecticide applications are the main control strategies for grape colaspis and rice water weevil (Hummel et al., 2014; Thrash et al., 2020). CrusierMaxx Rice and NipsIt Inside are the most commonly used insecticide seed treatments in rice. Both of these products are neonicotinoids and are highly efficacious on grape colaspis. They provide control of rice water weevil as well but can be less consistent than other treatments. Neonicotinoid seed treatments typically only last 28–35 days after planting. In many cases, rice planted in April will take 45–60 days to get to permanent flood. By this point, these seed treatments are no longer providing sufficient control of rice water weevil. The diamide seed treatments Dermacor X-100 and Fortenza have a longer residual than neonicotinoid seed treatments and provide consistent control of rice water weevil, but neither are as efficacious on grape colaspis as CruiserMaxx Rice or NipsIt Inside. Foliar insecticides can be effective at controlling rice water weevils if timely applications are made; however, they are less consistent than insecticide seed treatments.

Rice is fertilized prior to flooding with nitrogen in the form of urea. Impregnating a pesticide on urea has been evaluated for control of multiple pests in rice (Bond et al., 2007), including rice water weevil (Way and Wallace, 1996). While the impregnated urea was effective at controlling rice water weevil, these studies used chemistry that is no longer labeled for use in rice. The objective of this study was to determine if impregnating urea with insecticides provides adequate control of rice water weevils compared to insecticide seed treatments.

Procedures

An experiment was conducted in 2021 at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC) near Stuttgart, Arkansas, and Pine Tree Research Station (PTRS) near Colt, Arkansas. Diamond was planted at the RREC location on 6 April, and RT7321FP was planted at PTRS on 27 April. Multiple insecticide seed treatments, including a fungicide only untreated control (UTC) (Table 1), were compared to chlorantraniliprole (Prevathon) at 14 oz/ac, Clothianidin (Belay) at 4 oz/ac, and Zeta-Cypermethrin (Mustang) at 4 oz/ac coated on urea. Urea was applied to plots 24 h prior to permanent flood establishment. Rice water weevil densities were evaluated 33 and 21 days after permanent flood establishment for the RREC and PTRS, respectively. Larval densities were deter-

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mined by taking 3 core samples per plot with a 4-in. core sampler. Core samples were then washed through a series of sieves and examined in a saltwater solution. All rice water weevil larvae were counted per plot. 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

Rice Water Weevil Control

At the RREC and PTRS locations, all treatments except the clothianidin-treated urea and zeta-cypermethrin-treated urea treatments reduced rice water weevil densities compared to the UTC. The cyantraniliprole- and chlorantraniliprole-treated plots had lower rice water weevil densities than all other treatments except the chlorantraniliprole-treated urea plots (Figs. 1 and 2).

Grain Yield

Cyantraniliprole-, chlorantraniliprole-, and clothianidin-treated seed, and chlorantraniliprole-treated urea yielded higher than the UTC at the RREC location. Additionally, thiamethoxam treated-seed, and clothianidin-treated urea did not differ from any treatment (Fig. 3). Only cyantraniliprole- and chlorantraniliprole-treated seed yielded higher than the UTC at the PTRS location (Fig. 4).

Practical Applications

Across both locations, insecticide seed treatments provided more consistent control of rice water weevil than insecticide-treated urea, with the exception of chlorantraniliprole-treated urea. A similar trend was observed for yield. This data suggest that insecticide-treated urea could be a control option for growers to control rice water weevils, but more work is needed to determine the best product, rate, and timing for this strategy. For now, growers can expect more consistent control and increased yields with insecticide seed treatments compared to insecticide-treated urea.

Acknowledgments

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

Literature Cited

Bond, J.A., T.W. Walker, E.P. Webster, N.W. Buehring, and D.L. Harrell. (2007). Rice cultivar response to penoxsulam. Weed Technol. 21(4):961-965.

Hummel, N.A., A. Mészáros, D.R. Ring, J.M. Beuzelin, and M.J. Stout. (2014). Evaluation of seed treatment insecticides for management of the rice water weevil, *Lissorhoptrus oryzophilus* Kuschel (Coleoptera: Curculionidae), in commercial rice fields in Louisiana. Crop Protection 65:37-42.

Lorenz, G., N. Bateman, J. Hardke, and A. Cato. 2018. Insect management in rice. In: J.T. Hardke (ed.). Arkansas Rice Production Handbook. University of Arkansas System Division of Agriculture Cooperative Extension Service. MP192 pp. 139. Available at: https://www.uaex.uada.edu/publications/pdf/mp192/mp192.pdf

Thrash, B.C., G.M. Lorenz, N.R. Bateman, N.M. Taillon, S.G. Felts, W.A. Plummer, W.J. Plummer, J.K. McPherson, T.L. Clayton, C.A. Floyd, and C. Rice. 2020. Insecticide Seed Treatment Combinations for Control of Rice Water Weevil. In: K.A.K. Molderhauer, B. Scott, and J.T. Hardke (eds.) B.R. Wells Arkansas Rice Research Studies. 2019. University of Arkansas System Division of Agriculture Agricultural Research Station Research Series 667:93-96. Fayetteville.

Way, M.O. and R.G. Wallace. Control of Rice Water Weevil with Fipronil, 1995. Arthropod Management Tests 21.1 (1996):281-282.

Table 1. List of insecticide seed treatments and rates in the experiments at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC) near Stuttgart, Arkansas, and Pine Tree Research Station (PTRS) near Colt, Arkansas.

Insecticide Seed Treatment	Rate	Insecticide Class
Fungicide Only (UTC)[a]		
Thiamethoxam (CruiserMaxx Rice)	7 oz/cwt	Neonicotinoid
Clothianidin (NipsIt Inside)	1.9 oz/cwt	Neonicotinoid
Chlorantraniliprole (Dermacor X-100)	2.5 oz/cwt (RREC) 5 oz/cwt (PTRS)	Diamide
Cyantraniliprole (Fortenza)	3.47 oz/cwt	Diamide

[a] UTC = untreated control.

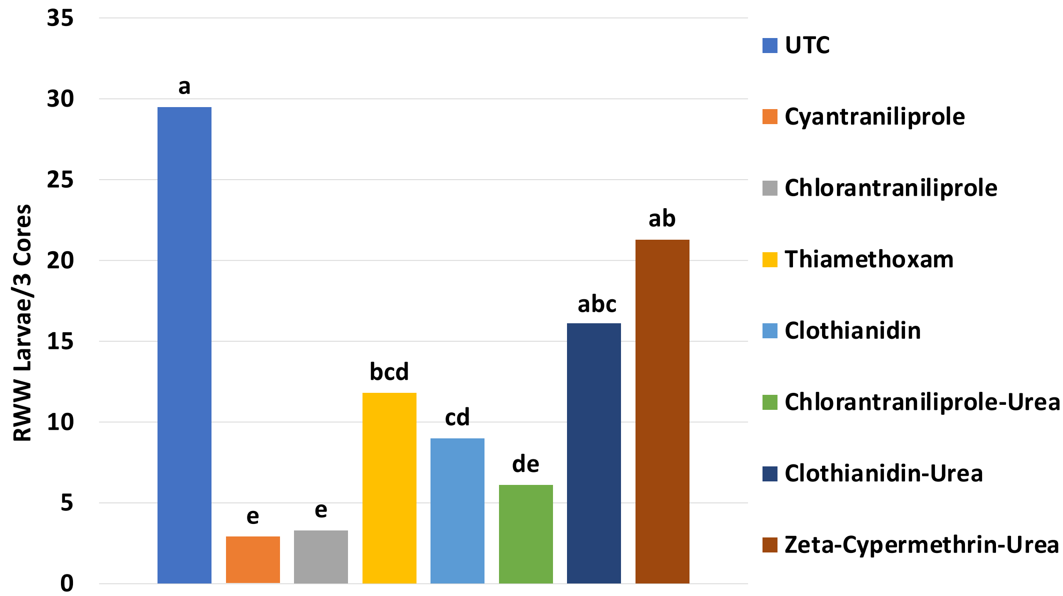

Fig. 1. Rice water weevil control comparing multiple insecticide seed treatments and insecticide-impregnated urea to a fungicide only treatment (UTC = untreated control) at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center, Stuttgart, 2021. Means followed by the same letter are not significantly different (α = 0.05).

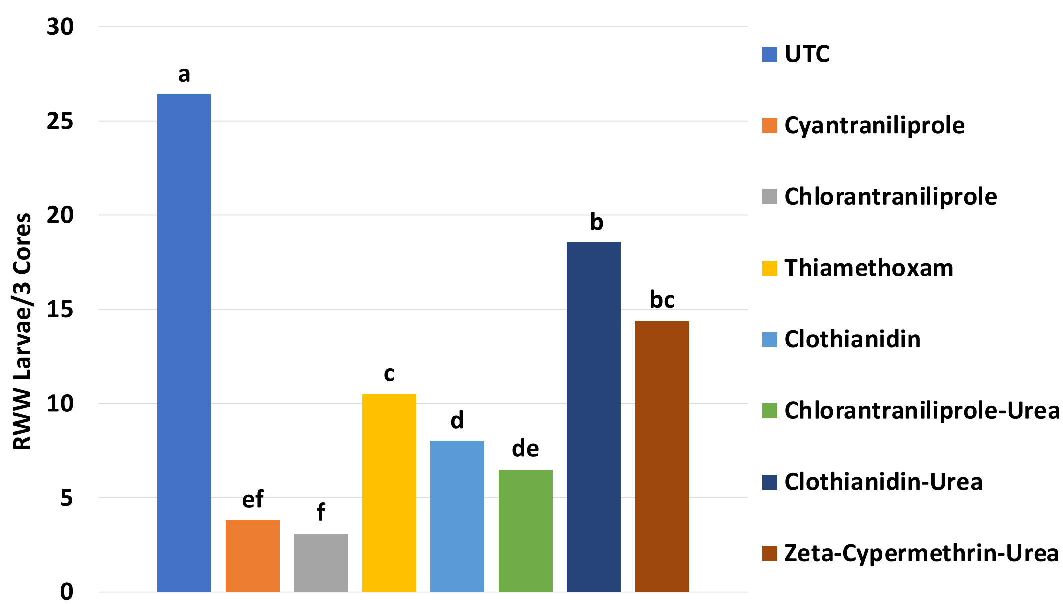

Fig. 2. Rice water weevil control comparing multiple insecticide seed treatments and insecticide-impregnated urea to a fungicide only treatment (UTC = untreated control) at the University of Arkansas System Division of Agriculture's Pine Tree Research Station, Colt, 2021. Means followed by the same letter are not significantly different (α = 0.05)

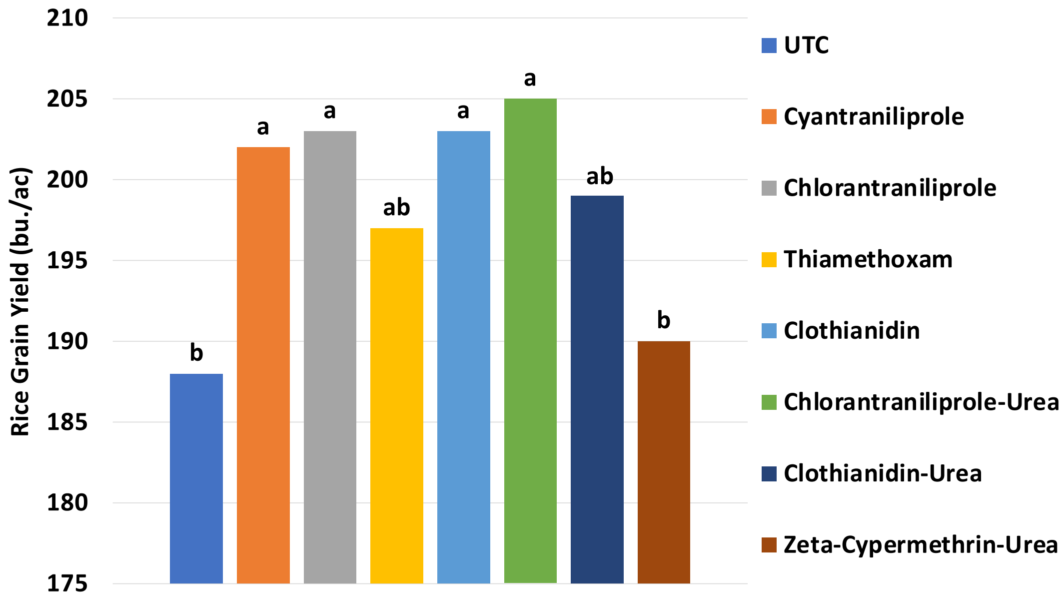

Fig. 3. Rice grain yield comparing multiple insecticide seed treatments and insecticide-impregnated urea to a fungicide only treatment (UTC = untreated control) at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center, Stuttgart, 2021. Means followed by the same letter are not significantly different (α = 0.05)

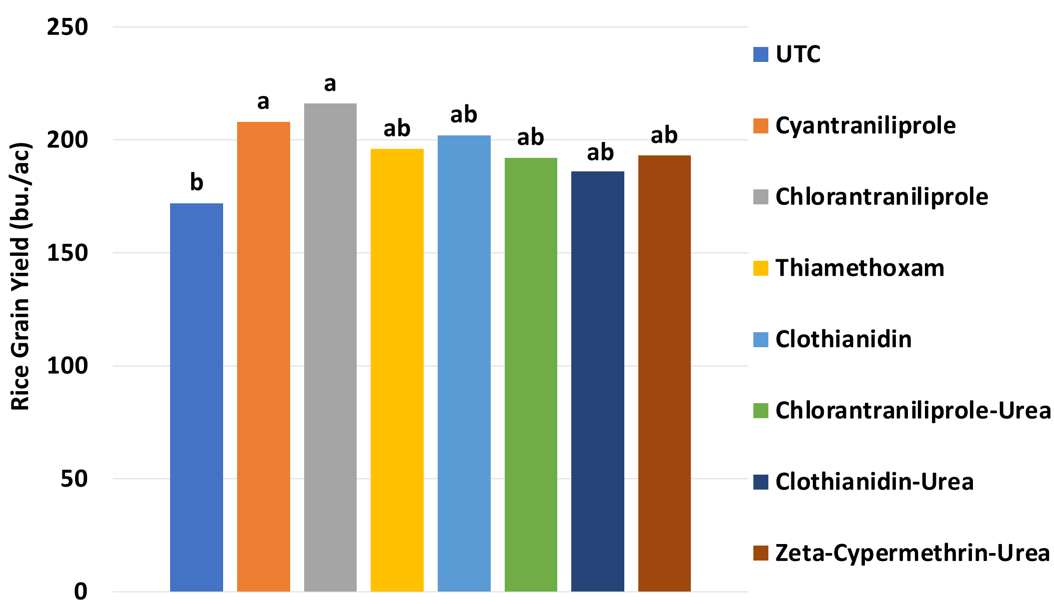

Fig. 4. Rice grain yield comparing multiple insecticide seed treatments and insecticide-impregnated urea to a fungicide only treatment (UTC = untreated control) at the University of Arkansas System Division of Agriculture's Pine Tree Research Station, Colt, 2021. Means followed by the same letter are not significantly different (α = 0.05)

Economic Analysis of Insecticide Seed Treatments in Rice

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Abstract

Grape colaspis and rice water weevil (RWW) are the two most important insect pests of rice in Arkansas. The main control strategy for both of these pests is using insecticide seed treatments. CruiserMaxx Rice and NipsIt INSIDE, both neonicotinoids, have shown excellent control of grape colaspis but can have a short residual and not provide adequate control of rice water weevil. The diamides, Dermacor X-100 and Fortenza, provide excellent control of rice water weevil but do not provide adequate control of grape colaspis. Combining a neonicotinoid seed treatment and a diamide seed treatment may provide better control of the seedling pest complex compared to these products alone and may enhance overall RWW control when planting early in the spring when cool, wet weather delays growth and permanent flooding. The purpose of these trials was to evaluate insecticide seed treatment combinations for efficacy of rice water weevils, yield benefits, and economic returns. The results of these studies suggest combinations of diamide and neonicotinoid insecticide seed treatments have the potential to reduce rice water weevil density, increase yield, and improve economic returns in conventional and hybrid rice varieties over standalone seed treatments.

Introduction

Insecticide seed treatments (ISTs) are used on 70–80% of rice acreage in Arkansas to control rice water weevil (RWW), grape colaspis (GC), and other pests. In previous studies, ISTs have been shown to improve stand counts and increase yields 80% of the time (Taillon et al., 2015). These treatments are also convenient and provide a more reliable option for RWW control when compared to foliar applications (Taillon et al., 2013).

In Arkansas, when growers plant early while the weather is still cool and tends to be wet, permanent flood is often delayed. Neonicotinoid seed treatments such as thiamethoxam (CruiserMaxx Rice) and clothianidin (NipsIt INSIDE) are very effective for early season control of GC, while diamides such as chlorantraniliprole (Dermacor X-100) and cyantraniliprole (Fortenza) are not. Previous studies indicate the residual control for neonicotinoids is only about 28–35 days. Diamides are very effective in controlling RWW and have a residual of 60–70 days or more (Taillon et al., 2017). This would indicate that a combination of a neonicotinoid and a diamide might provide better control of the seedling pest complex compared to these products alone and enhance control of RWW. The objectives of this study were to evaluate combinations of ISTs for control of RRW in conventional and hybrid rice and to determine if combinations of ISTs would provide increased control of RWW and value for growers in Arkansas.

Procedures

Small plot trials were conducted in 2019, 2020, and 2021 at the University of Arkansas System Division of Agriculture's Pine Tree Research Station (PTRS) near Colt and at the Rice Research and Extension Center (RREC) in Stuttgart. The experimental plot design was a randomized complete block with 4 replications. A hybrid cultivar and Diamond were planted at PTRS at 20 lb/ac and 70 lb/ac, respectively, and Diamond was planted at RREC at 70 lb/ac each year. Treatments included: Fungicide Only, NipsIt INSIDE (clothianidin) 1.92 fl oz/cwt, CrusierMaxx Rice (thiamethoxam) 7 oz/cwt, Dermacor X-100 (chlorantraniliprole) 2.5 fl oz/cwt or 5 fl oz/cwt (conventional or hybrid, respectively), and Fortenza 3.47 oz/cwt, as well as combinations of NipsIt INSIDE + Dermacor, NipsIt INSIDE + Fortenza, NipsIt INSIDE + CruiserMaxx, CruiserMaxx + Dermacor, and CruiserMaxx + Fortenza.

Rice water weevil larvae were evaluated by taking 3 core samples per plot with a 4-in. core sampler 21 days after permanent flood establishment. Samples were evaluated at the Lonoke 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. Economic analysis was conducted by obtaining the price of grain (USDA-NASS, 2022), seed cost from the University of Arkansas System Division of Agriculture's Enterprise Budgets, and seed treatment cost from informal surveys of retailers around the state. All data were processed using PROC GLIMMIX in SAS v 9.4 (SAS Institute, Cary, N.C.) with an alpha level of 0.05. Data were analyzed by individual seed treatments and seed treatment combinations, as well as by insecticide class.

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Results and Discussion

Rice Water Weevil Control

All insecticide treatments reduced rice water weevil densities lower than the fungicide-only treatment (Table 1). Also, all treatments containing Fortenza and Dermacor X-100 reduced rice water weevil densities lower than NipsIt Inside or CruiserMaxx Rice alone but was not better than NipsIt Inside in combination with CruiserMaxx Rice. When analyzed by insecticide class, combinations and diamide seed treatments provided greater efficacy than all other treatments (Fig. 1).

Grain Yield

All insecticide seed treatments yielded greater than the untreated control (Table 1). The combination of CruiserMaxx Rice plus Dermacor X-100 yielded higher than all other treatments, except NipsIt Inside plus Dermacor X-100, NipsIt Inside plus Fortenza, CruiserMaxx Rice plus Fortenza, and Dermacor X-100. A general trend was observed that treatments containing a diamide seed treatment yielded higher than those without. When analyzed by insecticide class, combinations and diamide seed treatments yielded higher than neonicotinoid seed treatments alone and the fungicide-only treatment (Fig. 2).

Net Returns

All insecticide seed treatments provided greater net returns than the fungicide only (Table 1). CruiserMaxx Rice plus Dermacor X-100 had greater net returns than NipsIt Inside and CruiserMaxx Rice plus NipsIt Inside. No differences were observed among diamide seed treatments alone or in combination with a neonicotinoid. When analyzed by insecticide class, an interaction was observed between conventional and hybrid cultivars (Fig. 3). In general, conventional cultivars had higher net returns than hybrid cultivars; however, a similar trend of combinations of insecticide seed treatments providing higher net returns was observed for both cultivar types.

Practical Applications

Overall, diamide seed treatments alone or in combination with a neonicotinoid seed treatment reduced rice water weevil densities, had greater yields, and improved net returns over a neonicotinoid seed treatment. This data supports growers incorporating diamide seed treatments in their production practices. In areas where both grape colaspis and rice water weevil are a concern, the combination of neonicotinoid and diamide seed treatment is recommended.

Acknowledgments

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

Literature Cited

Taillon, N.M., G.M. Lorenz III, W.A. Plummer, M.E. Everett, H.M. Chaney, B.C. Thrash, D.L. Clarkson, and L.R. Orellana Jimenez. 2014. A Historical Look at Rice Insecticide Seed Treatments from 2007 to 2013: Where Are We Now? *In*: B.R. Wells Arkansas Rice Research Studies 2013. University of Arkansas Agricultural Research Station Research Series 617:174-181. Fayetteville.

Taillon, N.M., G.M. Lorenz, W.A. Plummer, H.M. Chaney, and J. Black. 2016. Value of Insecticide Seed Treatments in Arkansas Rice. *In*: B.R. Wells Arkansas Rice Research Studies 2015. University of Arkansas Agricultural Research Station Research Series 634:152-158. Fayetteville.

Taillon, N.M., G.M. Lorenz, W.A. Plummer, K. McCullars, A.J. Cato, and J.L. Black. 2018. Evaluation of Insecticide Seed Treatment Combinations for Control of Rice Water Weevil, *Lissorhoptrus oryzophilus*. *In*: B.R. Wells Arkansas Rice Research Studies 2017. University of Arkansas Agricultural Research Station Research Series 651:176-179.

USDA NASS. 2022. United States Department of Agriculture National Agricultural Statistics Service. Data and Statistics. https://quickstats.nass.usda.gov/

Table 1. Rice water weevil control, yield benefits, and net returns with insecticide seed treatments in rice.

Insecticide Seed Treatment	RWW[†] Control	Yield	Net Returns
		(bu./ac)	(U.S.$/ac)
Fungicide Only	30.7 a[‡]	182.9 e	910.1 d
CrusierMaxx Rice	15.4 b	200.6 bcd	1001.9 abc
NipsIt Inside	13.7 bc	197.7 d	993.6 bc
Dermacor X-100	6.0 d	203.6 abc	1017.3 abc
CruiserMaxx Rice + Dermacor X-100	5.9 d	208.5 a	1031.2 a
NipsIt Inside + Dermacor X-100	7.6 d	205.4 ab	1020.1 abc
Fortenza	5.7 d	202.4 bcd	1010.7 abc
CruiserMaxx Rice + Fortenza	6.3 d	204.5 abc	1011.0 abc
NipsIt Inside + Fortenza	5.9 d	205.5 ab	1024.0 ab
Cruisermaxx Rice + NipsIt Inside	9.8 cd	199.8 cd	989.4 c
P-value	<0.01	<0.01	<0.01

[†] Rice water weevil per 3 cores.

[‡] Means followed by the same letter are not significantly different at an alpha level of 0.05.

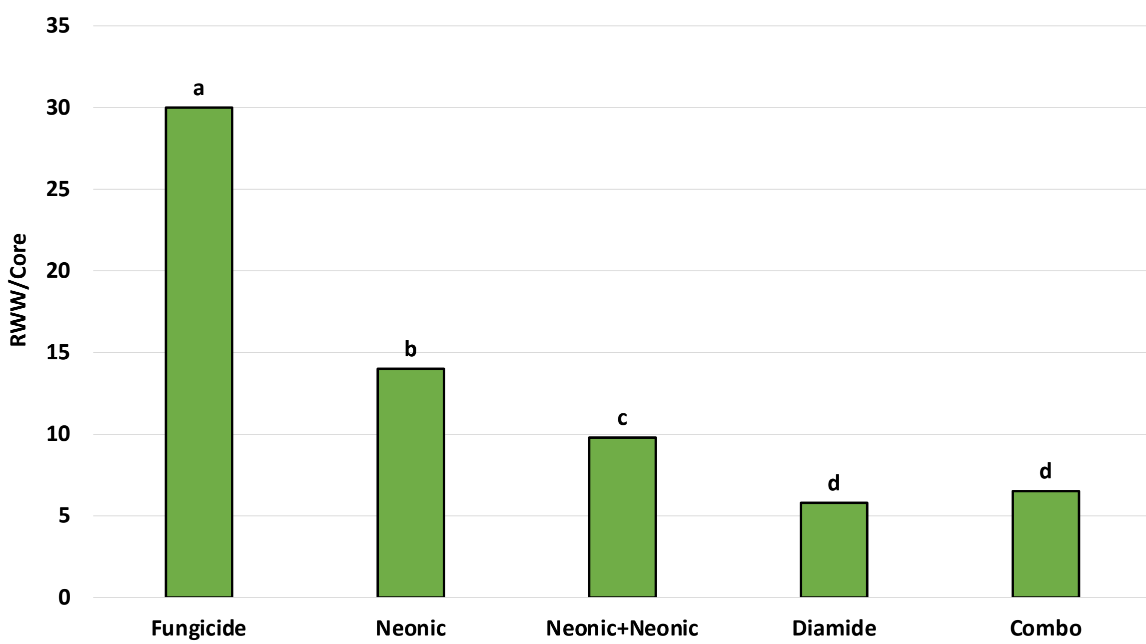

Fig. 1. Rice water weevil control comparing insecticide seed treatments and insecticide seed treatment combinations to a fungicide only treatment across 8 trials from 2018 to 2021. Means followed by the same letter are not significantly different at an alpha level of 0.05.

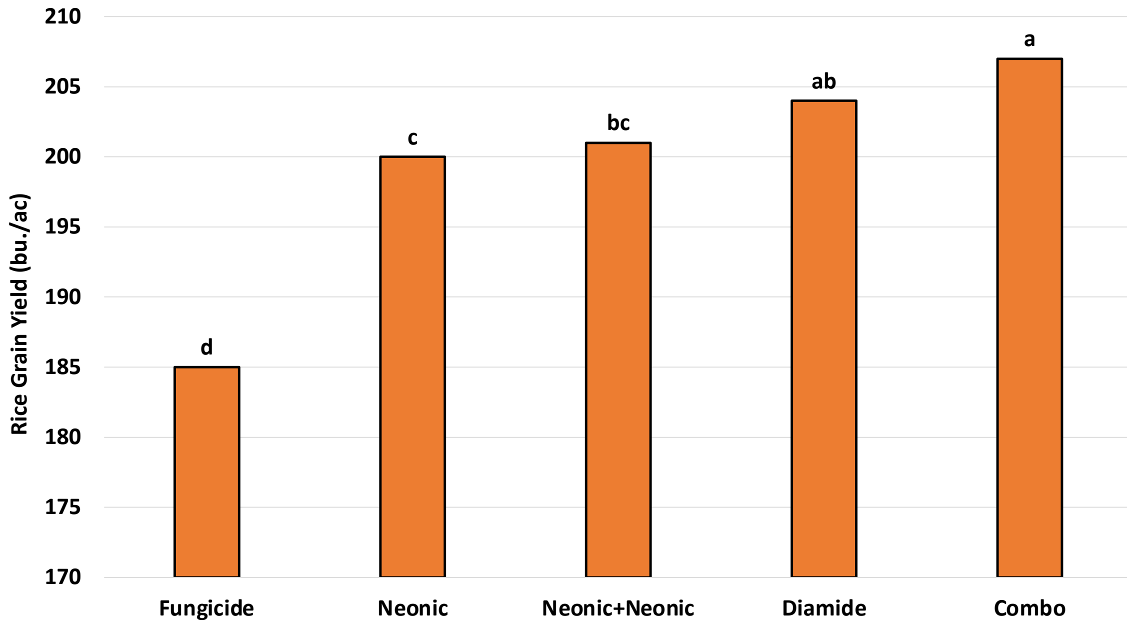

Fig. 2. Rice grain yield in bushels per acre, comparing multiple insecticide seed treatment and insecticide seed treatment combinations to a fungicide-only treatment across 8 trials from 2018 to 2021. Means followed by the same letter are not significantly different at an alpha level of 0.05.

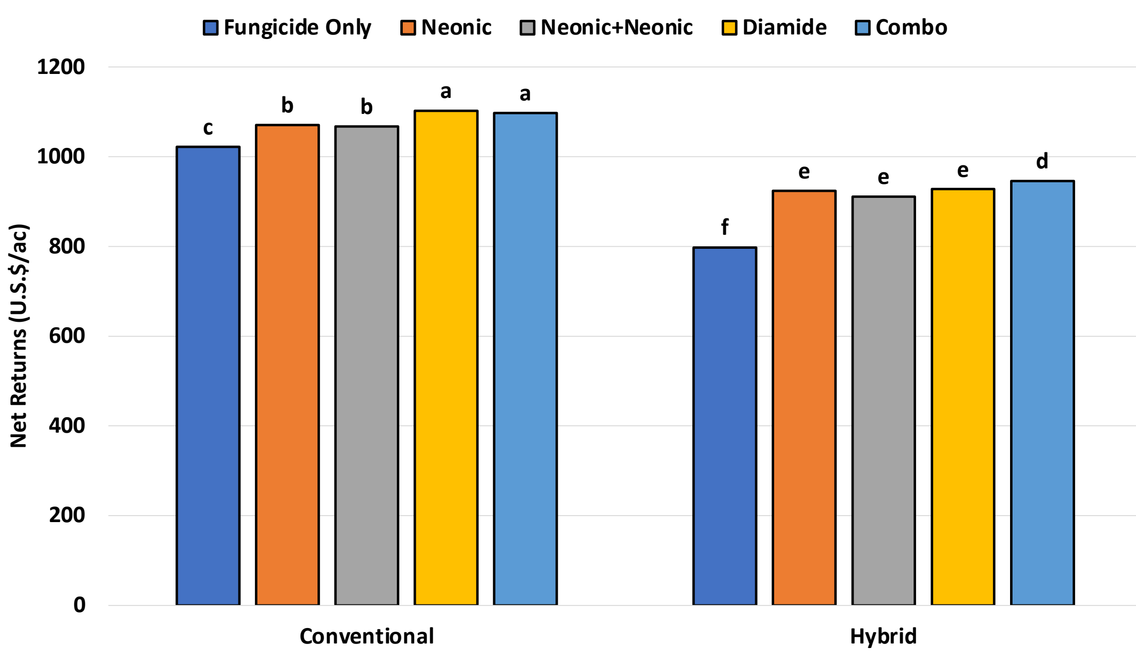

Fig. 3. Net returns in U.S. dollars for multiple insecticide seed treatments and insecticide seed treatment combinations for conventional and hybrid rice from 2018 to 2021. Means followed by the same letter are not significantly different at an alpha level of 0.05. Combo refers to a combination of a neonic seed treatment and diamide seed treatment.

Development of Defoliation Thresholds in Rice

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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. The two main armyworm species observed in rice in this region are true armyworms and fall armyworms. It is common to see infestations occur at all growth stages of rice. The current threshold for armyworms in rice is based on the number of larvae per square foot. A defoliation-based threshold would provide growers and consultants with a simple way to make economically sound decisions for controlling armyworms in rice. Studies were conducted in 2019, 2020, and 2021 where rice was mechanically defoliated at 0%, 33%, 66%, and 100% with a weed eater at 2–3 leaf, early tiller, late tiller, and green ring growth stages across three planting dates. Large amounts of yield loss were observed when plants were defoliated either 66% or 100% at the green ring growth stage. A delay in heading was observed when high levels of defoliation occurred at late tiller in the green ring stage, with later plantings having more delay than earlier plantings. This data has helped form a defoliation-based threshold in rice to help keep rice growers profitable.

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 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-based threshold would be easier to use and a better option for growers. The objective of this study was to determine the impact of defoliation on the yield and growth of rice across multiple planting dates and growth stages, and to determine a defoliation-based threshold for rice.

Procedures

Studies were conducted at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center, Stuttgart, Arkansas, in 2019, 2020, and 2021 to determine the impact defoliation has on rice across multiple planting dates. Diamond was drill seeded at 70 lb/ac on 8 April, 1 May, and 1 June. Plots were 8 rows (7.5-in. spacing) by 16.5 ft. Defoliation was simulated using an electric weedeater at the 2–3 leaf, early tiller, late tiller, and green ring growth stages. Plots were defoliated either 0, 33%, 66%, or 100%. The 100% defoliation level at the 2–3 leaf growth stage was defoliated all the way to the soil line, but for all other growth stages, the 100% defoliation was defoliated to the water line. Plots were arranged in a randomized complete block design with 6 replications within each planting date. Days to 50% heading were recorded for all plots to determine maturity delays associated with defoliation. 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

No yield loss was observed for the 2–3 leaf or early tiller growth stages for the April planting. A small amount of yield loss was observed when defoliation exceeded 80% at the late tiller growth stage. And major yield losses were observed for the green ring defoliation timing when defoliation exceeded 30% (Fig. 1). A similar trend was observed for May and June plantings for the 2–3 leaf and early tiller growth stages (Figs. 2 and 3). Little yield loss was observed at any level of defoliation for the late tiller timing for May plantings; however, for June plantings, yield losses increased when defoliation exceeded 40%. For May and June plantings, yield losses at the green ring timing were similar to that of April plantings.

No heading delays were observed for the 2–3 leaf growth stage for any planting date. Heading delays were observed for high levels of defoliation at the early tiller growth stage for the June planting only. For both the late tiller growth stage and green ring growth stage, heading delays were observed for all plantings, with higher defoliation levels being worse. (Table 1).

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Overall, defoliation did not severely impact yield or maturity for the April planting unless the defoliation occurred at the green ring growth stage. The May and June plantings were impacted worse than the April planting, with major yield loss and heading delays observed when defoliation occurred during the late tiller or green ring growth stages. Temperature effects could account for the difference in yield loss at the green ring growth stage between May and June plantings, as well as the heading delay observed between 2019 and 2020. Further analysis of heat units is needed to determine what impact temperature has on the recovery of rice after defoliation occurs.

Practical Applications

These data have allowed us to develop a defoliation-based threshold that will ensure growers stay profitable. The new defoliation threshold in rice is no applications are needed for 2–3 leaf and early tiller growth stages across all plantings; but if soil is cracking and armyworms can feed on the growing point, then applications may be warranted. For May and June plantings, applications are needed if defoliation exceeds 40% at the late tiller growth stage or if defoliation exceeds 20% at the green ring stage. Applications may also be needed if head clipping is occurring in heading rice. These thresholds will eliminate unwarranted sprays for early season defoliation, as well as for small amounts of defoliation observed at later growth stages. The elimination of these insecticide applications will also help preserve beneficial insects that aid in the control of major pests, such as rice stink bug.

Acknowledgments

The authors would like to express their appreciation for the Arkansas Rice Checkoff Program administered by the Arkansas Rice Research and Promotion Board and the University of Arkansas System Division of Agriculture.

Literature Cited

Lorenz, G., Bateman, N., Hardke, J., Cato, A. 2018. Insect Management in Rice. In: Arkansas Rice Production Handbook. University of Arkansas System Division of Agriculture Cooperative Extension Service. MP192 pp. 139-162. Available at: https://www.uaex.uada.edu/publications/pdf/mp192/chapter-12.pdf

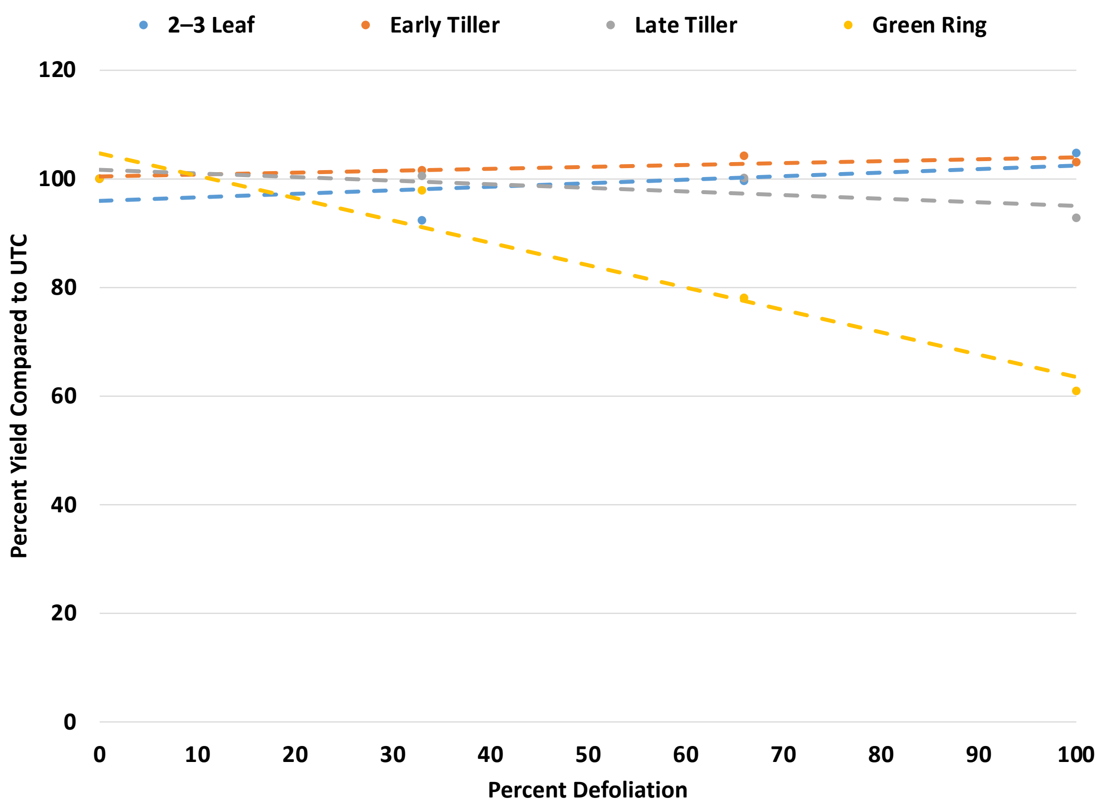

Fig. 1. Yield impacts caused by varying levels of defoliation in studies conducted from 2019 to 2021 at multiple growth stages for April-planted rice compared to the untreated control (UTC).

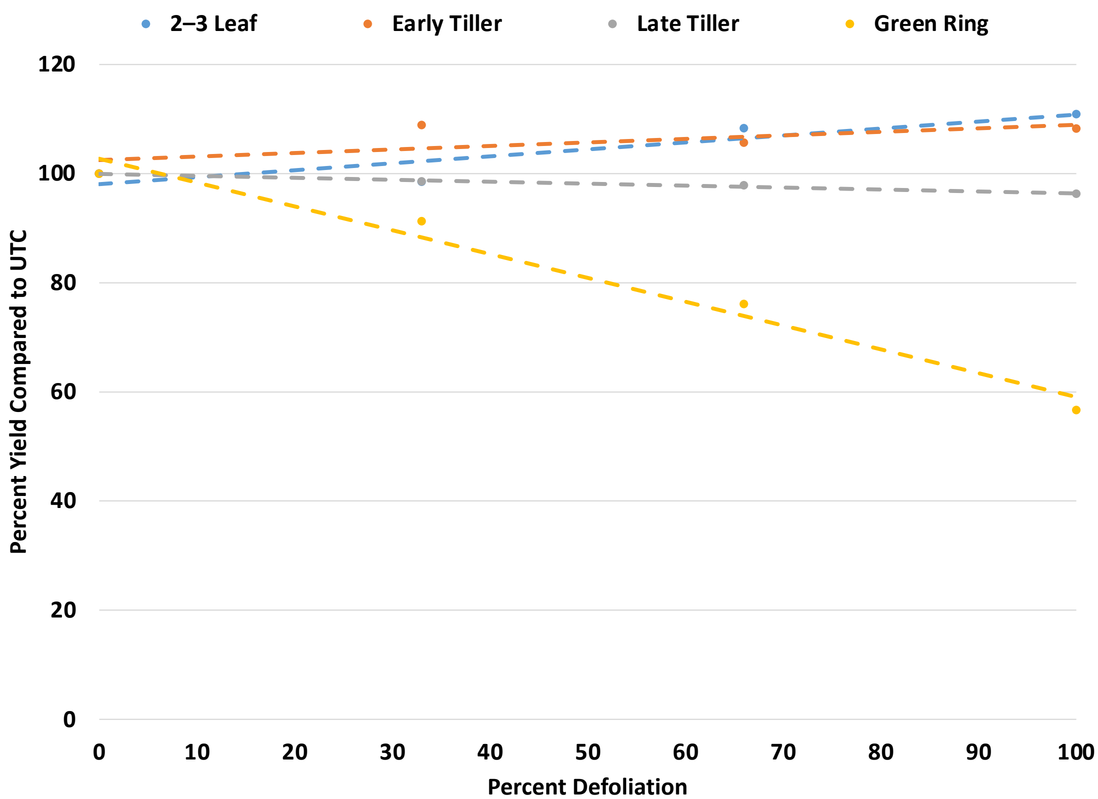

Fig. 2. Yield impacts caused by varying levels of defoliation in studies conducted from 2019 to 2021 at multiple growth stages for May-planted rice compared to the untreated control (UTC).

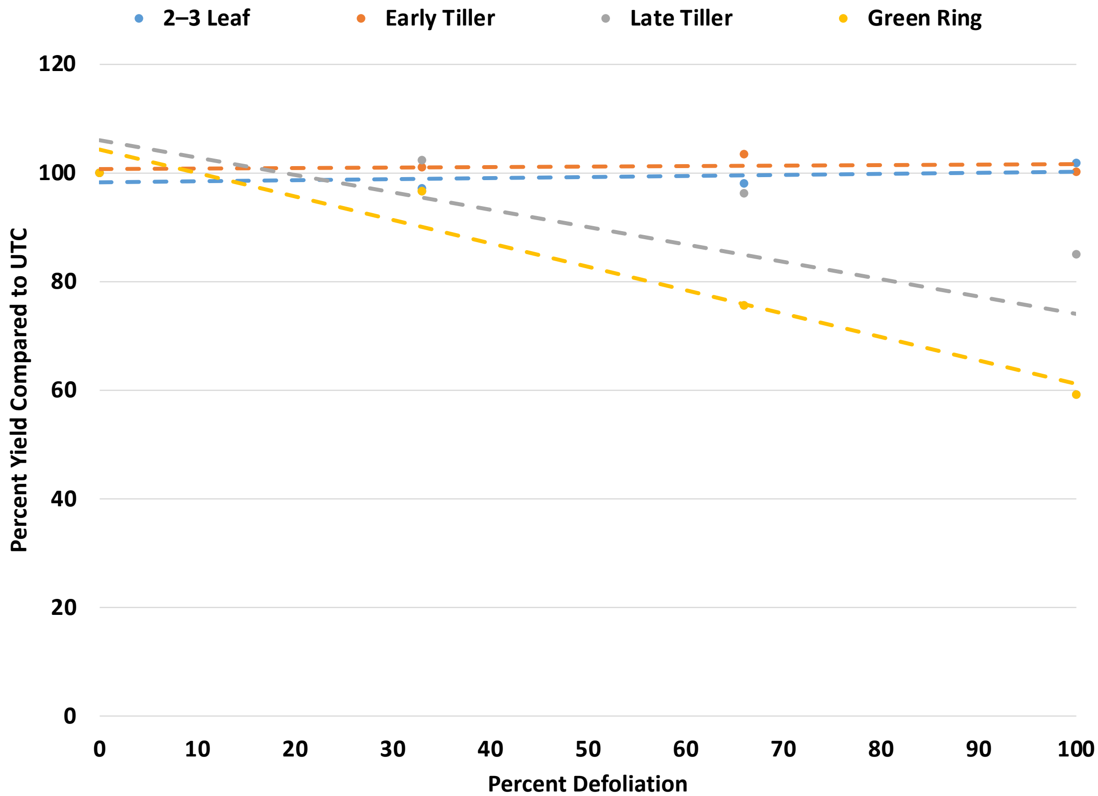

Fig. 3. Yield impacts caused by varying levels of defoliation in studies conducted from 2019 to 2021 at multiple growth stages for June-planted rice compared to the untreated control (UTC).

Table 1. Days in delayed heading in rice caused by defoliation at multiple growth stages for studies conducted in 2019 and 2020 at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center, Stuttgart, Ark.

		Planting Date		
Growth Stage	**% Defoliation**	**April**	**May**	**June**
2–3 leaf	0	0.0 e[†]	0.0 e	0.0 f
	33	0.0 e	0.0 e	0.3 f
	66	0.0 e	0.0 e	0.4 f
	100	3.0 cd	0.9 e	2.2 d
Early Tiller	0	0.0 e	0.0 e	0.0 f
	33	0.3 e	0.9 e	1.1 ed
	66	1.0 e	1.2 e	1.8 d
	100	1.9 d	2.5 d	4.6 c
Late Tiller	0	0.0 e	0.0 e	0.0 f
	33	1.8 d	3.2 c	5.4 c
	66	3.2 c	4.4 c	8.6 b
	100	8.1 b	8.1 b	10.8 b
Green Ring	0	0.0 e	0.0 e	0.0 f
	33	4.7 c	6.9 bc	9.1 b
	66	7.3 b	11.1 ab	15.0 ab
	100	10.0 a	14.9 a	18.9 a
***P*-value**		<0.01	<0.01	<0.01

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

Evaluating the Distribution and Monitoring Systems for Rice Billbug (*Sphenophorus pertinax*) in Furrow Irrigated Rice

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Abstract

Furrow irrigated rice (FIR) production acreage is increasing in Arkansas due to potential cost savings on tillage and levee construction when compared to flood irrigated rice. In a FIR system, there is a lack of standing water across the top portion of the field, which increases the field's susceptibility to rice billbug (*Sphenophorus pertinax*). Rice billbugs feed on the roots and tillers of rice plants, causing rice seed heads to abort and yield loss to occur. As furrow irrigated production systems increase across Arkansas, so has the demand for rice billbug monitoring strategies. A survey was conducted across four states in furrow-irrigated fields to monitor billbug distribution. Studies were also conducted in three FIR fields in Arkansas to evaluate trapping and monitoring methods for rice billbugs using multiple insect trap styles.

Introduction

In the Mid-southern U.S., Arkansas, Louisiana, Missouri, and Mississippi are prominent rice-growing states, responsible for 77% of total rice harvested nationally in 2021 (USDA-NASS, 2021). Furrow irrigated rice (FIR) production has increased in recent years as rice producers seek a more cost-saving rice production practice through reduced labor and equipment use. This system has the potential to reduce fuel costs due to reduced tillage and levee construction. Moving to a furrow irrigated production system has altered the field environment allowing it to be more favorable to non-typical rice pests. Rice billbug is considered a minor rice pest in the traditional flooded system, typically only found feeding on rice planted on the levees. Without the presence of a flood and increased plant density for cover, FIR has become a favorable host for billbug (Dupuy and Ramirez, 2016). Very little research has been conducted on rice billbug biology and monitoring, and fundamental research is needed to understand the impact and yield loss associated with rice billbug in a FIR system. The objectives of this study are to determine rice billbug distribution in the Mid-southern U.S. and analyze different trapping methods to create a successful monitoring program.

Procedures

Monitoring Systems for Rice Billbug

An experiment was conducted at one FIR location in Jackson County during the 2019, 2020, and 2021 growing seasons. RiceTec RT CLXL7311 hybrid in 2019, RiceTec RT7301 in 2020, and RiceTec 7321FP were selected for their high rice blast resistance and were planted at a rate of 22 lb/ac. Eight styles of traps were evaluated to determine the best method for monitoring rice billbugs entering the field: colored buckets, pitfall traps, several ground cover methods, flight interception traps, light traps, sticky cards, and pyramid traps. Each trap was checked weekly, starting with the first week in May for sixteen consecutive weeks.

Bucket. A series of six five-gallon buckets were placed on the rice field edge separating the possible overwintering site from the production field. Six colors, pink, green, blue, orange, yellow, and gray, were placed in random order along the tree line and were replicated four times at each location. Buckets were moved laterally each week to allow fresh grass to remain under the buckets. Each bucket was checked weekly, and specimens were collected from the grass under each bucket.

Pitfall Trap. Four linear pitfall traps were buried in the plant bed closest to the turn row, with the top of the trap level with the soil surface. Pitfalls were made from 4-in. PVC pipe that was 4 ft in length and with a 1.5-in. slit cut in the top and capped at one end. The other end is equipped with a plastic collection container. Linear pitfalls were buried at a slight angle where the lowest point of the grade leads to the collection container. Insects that fall into the trap are forced to travel into the collection container.

Ground Cover Methods. A series of different materials were placed along the field edge and monitored weekly to determine if billbug adults would seek cover under the materials. An 8 ft × 8 ft tarp was spread tightly and staked into the ground on top of the soil surface of the turn row. Multiple pieces of plywood, in 3 ft × 3 ft sections, were placed on turn rows as well as 4-ft segments of 4-in. PVC pipe sections that were painted pink.

Flight Interception Trap. Additionally, two flight interception traps were constructed and placed in each experiment location to account for billbug using flight to enter the field. Reports of species similar to rice billbug have been observed as weak fliers. Flight interception traps were designed to force heavier insects

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to compromise their trajectory and force them downward into the collection trough. A screen approximately 7.5 ft in height and 3.5 ft in width was placed in between assumed overwintering sites and production fields. Each trap was equipped with a collection trough placed on each side of the screen containing a non-toxic pink propylene glycol solution.

Light Trap. Another trap implemented was a universal light trap containing a halo fluorescent black light. Bulbs were controlled by photoelectric sensors that respond to changes in sunlight. Photoelectric sensors were connected to a deep cycle marine battery, which provided efficient power between collections. Batteries were replaced and recharged weekly throughout the experiment. The bucket was modified with an aluminum funnel to collect specimens within the bucket. Two light traps were placed at each location.

Sticky Cards. Four replications of sticky cards were placed on a wooden post at 3 ft and 7 ft from the soil surface and were distributed evenly throughout the top two-thirds of the field. Yellow 6 in. × 12 in. and orange 9 in. × 15 in. sticky cards were placed on alternating posts. Sticky cards received additional applications of insect collection adhesive. Sticky cards were replaced weekly.

Pyramid Traps. Two black pyramid insect traps were placed along the field edge. The traps were made of black corrugated plastic triangles standing 4 ft in height and staked into the soil. Pyramid trap design is intended to lure insects upward once they land on the trap. A plastic collection jar at the top of the trap encloses insects inside until collection counts can be taken.

All data were analyzed in PROC GLIMMIX SAS v 9.4 (SAS Institute, Cary N.C.).

Billbug Survey

A survey was conducted on 80 FIR fields across the 2019, 2020, and 2021 growing seasons in four states; Arkansas (64), Missouri (8), Louisiana (6), and Mississippi (2). Observations were taken of the surrounding landscape in the four cardinal directions around each field. At each location, three pink 5-gal buckets were distributed equally throughout the top two-thirds of the field, where billbug damage has been commonly found. Every week throughout the growing season, buckets were checked for adults, and fields were scouted for billbug larvae and damage. Once billbug damage was identified in the field, growth stage was collected to predict billbug migration into the field.

Results and Discussion

Billbug Monitoring

Bucket Color Preference. Data from 2019–2021 suggest that buckets that were colored pink numerically collected more billbug than any other color and were significantly greater than every color but gray (Fig. 1). These data suggest that pink is a preferred color by rice billbug, and rice billbug traps should implement the color.

Trap Style. Bucket traps and collection troughs generated the greatest percent of billbug specimens collected (Table 1). Traps designed for ground-active insects collected over 99% of the total billbugs for all years. Collections made under the collection troughs of the flight interception traps dramatically increased when the pink propylene glycol solution was used. This observation agrees with findings that were made in the color preference experiment for rice billbug. No billbugs were ever found inside the light trap but were rather found underneath the collection bucket. These data suggest collections made with traps designed for ground-active insects are better for monitoring billbugs than those designed for more flight-prone insects. These findings suggest that rice billbugs are likely crawling to infest rice fields rather than flying.

Billbug Survey

Rice billbug damage was observed at survey locations in both Arkansas and Missouri. Billbug damage was not found at any locations in Louisiana or Mississippi, though damage has been reported in these regions. Across the 53 survey locations during 2019, rice billbug damage and larvae were observed at 60% of fields. In Arkansas, 78% surveyed had a presence of rice billbug within the field in 2019, and 80% were infested in 2020. During the 2021 growing season, 93% of survey fields had billbug feeding observed. In Missouri, 50% of fields surveyed had a billbug infestation. Data pooled from all growing seasons show that of the fields that were infested with billbug, 82% had grassy borders. In contrast, of the sampled fields that were not bordering a grassy area, only 9% had an infestation of rice billbug. Plant vegetation surrounding FIR fields also influenced the risk of billbug infestation. Furrrow irrigated rice fields where tree lines were surrounding at least one side of the field had a 66% risk of infestation. Fields where solely natural grasses, or grassy turnrows were present, along with fields only surrounded by row crop production, had a reduced risk of infestation of 26% and 23%, respectively. These preliminary data suggest that billbug infestation is more likely in fields with at least one surrounding tree line, where early season food resources such as Bermuda grass (*Cynodon dactylon*) and sedges (Family:Cyperaceae) are available.

Observations suggest billbug migrations into FIR predominantly occurred prior to the 3–4 tiller growth stage. Observational greenhouse data shows damage affiliated with adult billbug feeding begins to show symptomology 5–7 days after initial feeding occurs. Data from both growing seasons suggested that initial symptoms from billbug feeding occur at the 3–4 tiller growth stage (60%). Infestation occurrences were not as common during 5–6 tiller (23%), green ring (9%), or boot (8%) growth stages.

Based on 2019–2021 trapping data, increasing billbug densities are observed during the last week in May, with a peak occurring during the first week in June. A second peak in billbug densities was observed in the 3rd week in July, but collection numbers were not as prominent as in the initial peak. Based on overwintering monitoring of billbugs, they can overwinter as adult, larvae, or pupae. A second migration to the field may suggest that early instar overwintering larvae that survive have cycled through development and are migrating to the field.

Practical Applications

Billbugs were prone to crawl under the base of all the tested trapping systems and remain on the soil surface while being hidden. The pink-colored buckets were more attractive than all other tested colors. Currently, research is being conducted to extract sex pheromones from rice billbugs in hopes of improving monitoring techniques. Together, these experiments have the potential to create a successful monitoring technique to develop a management strategy for rice billbug. This research will eventually aid Arkansas rice growers by detecting the presence of rice billbug, allowing for timely management strategies to protect yield potential.

Acknowledgments

We would like to thank the Arkansas Rice Promotion Board for funding this research through the Arkansas Rice Checkoff, as well as Stan Haigwood, Parmer Hankins, Brett Stewart, and Rice-Tec, Inc. for the use of their land, and the Arkansas Cooperative Extension Service county agents for their help with this project.

Literature Cited

Dupuy, M.M. and R.A. Ramierez. 2016. Biology and Management of Billbugs (Coleoptera: Curculionidae) in Turfgrass. J. Integrated Pest Management. Vol 7:1.

USDA-NASS. 2021. United States Department of Agriculture-National Agriculture Statistic Service. Quick Stats. Accessed 14 January 2021. Available at: https://quickstats.nass.usda.gov/results/7FF46876-A658-3A4A-AE03-ECE11673D46C

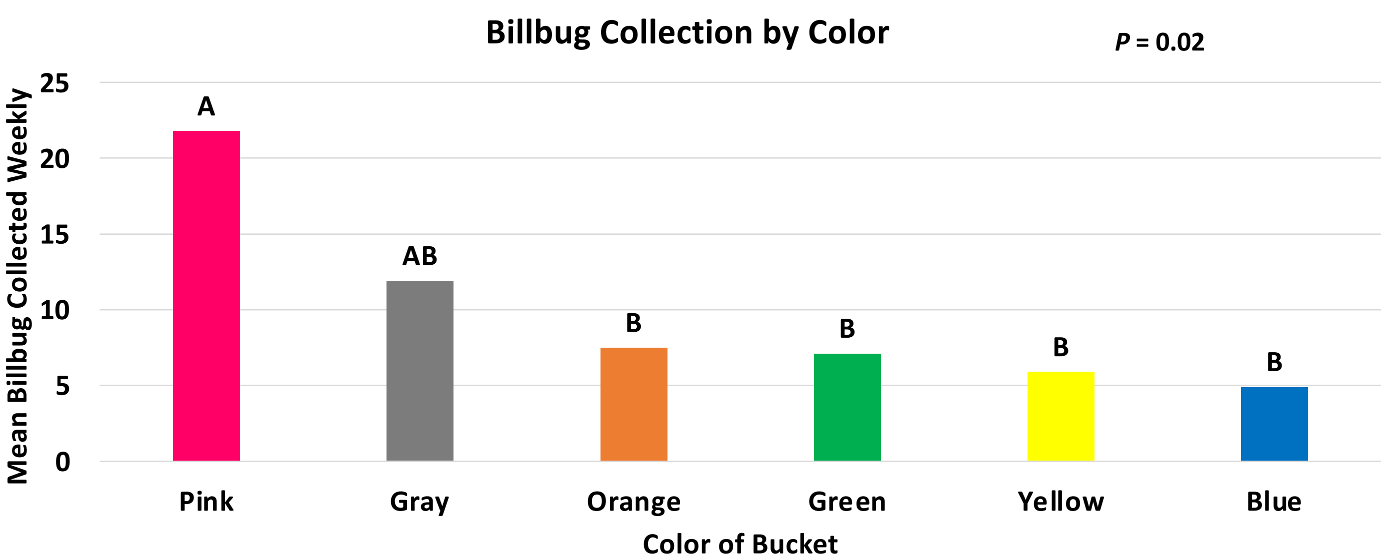

Fig. 1. Collection of rice billbug using different color traps. Treatments with the same letter are not significantly different according to Fisher's protected least significant difference test at α = 0.05.

Table 1. Weekly percentages of rice billbug collections using various style traps.

	Trapping System								
Date	Bucket[a]	Pitfall[a]	Tarp[a]	Trough[a,c]	Flight Interception[b]	Light[b]	Sticky Cards[b]	Pyramid[b]	Ground Cover[a]
	--(% of Weekly Collection Total)--								
WK 1[d]	0	0	0	0	0	100[c]	0	0	0
WK 2	56	38	0	6	0	0	0	0	0
WK 3	75	0	10	15	0	0	0	0	0
WK 4	60	4	2	35	0	1	0	0	0
WK 5	63	3	0	28	0	0	0	0	0
WK 6	57	0	0	43	0	0	0	0	0
WK 7	15	0	0	85	0	0	0	0	0
WK 8	41	0	0	59	0	0	0	0	0
WK 9	25	0	29	36	0	0	0	0	10
WK 10	72	0	0	28	0	0	0	0	0
WK 11	26	43	0	31	0	0	0	0	0
WK 12	32	0	0	61	0	0	0	0	7
WK 13	13	63	0	25	0	0	0	0	0
WK 14	25	0	0	50	0	0	0	0	25
WK 15	0	0	0	0	0	0	0	0	0
WK 16	34	0	0	66	0	0	0	0	0
WK 17	0	0	0	0	0	0	0	0	0
WK 18[e]	50	0	0	50	0	0	0	0	0
%Total	55%	14%	1.43%	29%	0%	>1%	0%	0%	>1%

[a] Traps designed for ground-active insects.
[b] Traps designed for flight-active insects.
[c] Billbugs were collected under the trap, not by designed method.
[d] Collection date started the first week in May.
[e] Collection date ended the last week in August.

Evaluation of Insecticide Seed Treatments in Furrow Irrigated Rice for Control of Rice Billbug (*Sphenophorus pertinax*)

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Abstract

Since 2018, furrow-irrigated rice (FIR) has accounted for approximately 15% of the total rice acres in Arkansas. Rice producers in Arkansas have increased FIR acreage to reduce labor and tillage, and easily rotate crops. The elimination of a flood across the field has made rice more susceptible to rice billbug (*Sphenophorus pertinax*). Historically, this insect has been considered a minor pest in traditional flood-irrigated production systems, occurring primarily on the levees in the field. Rice billbugs feed on the roots and tillers of rice plants, causing dead tillers, and rice panicles to abort, resulting in direct yield loss. As furrow-irrigated rice acreage continues to increase in Arkansas, a cost-effective management strategy for rice billbug is needed. Experiments were conducted in 2020 and 2021 to evaluate the effectiveness of insecticide seed treatments for the control of rice billbug. Neonicotinoid and diamide insecticide seed treatments, alone and in combination, were included in the study. Rice plots were monitored throughout the growing season for rice billbug damage. 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. Plots with a seed treatment containing a neonicotinoid in combination with a diamide product resulted in yields greater than the untreated check or a neonicotinoid alone. All insecticide seed treatments significantly increased yield when compared to the untreated check.

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 flooded rice system. Felts et al. (2019) found that combinations of neonicotinoids and diamide seed treatments resulted in higher yields than standalone insecticide seed treatments. Developing best management practices for rice billbug in row rice is imperative as the popularity of this production system continues to increase.

Procedures

Experiments were conducted in 2020 and 2021 at three FIR locations in Jackson County, Arkansas. RiceTec RT7301 (2020) and RiceTec RT7321FP (2021) long-grain hybrids rice were planted for their rice blast tolerance. 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). Two sampling methods were evaluated to measure yield losses associated with rice billbug feeding. Pre-heading sampling was conducted at the green ring growth stage by counting all damaged and undamaged tillers for all plants in 5 linear feet per plot. Post heading samples were taken during the third week of heading, and the total number of undamaged panicles and blank panicles were recorded for 5 linear feet per plot. All plots were harvested using a plot combine equipped with a harvest master system. Data were analyzed in PROC GLIMMIX with SAS v. 9.4 (SAS Institute, Cary, N.C.) at an alpha level of 0.05.

Results and Discussion

Significant differences between treatments were observed using the destructive sampling method. NipsIt + Fortenza had the lowest tiller damage and had less tiller feeding than the untreated or NipsIt alone (Fig. 1). No differences were observed for blank

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panicle sampling (Fig. 2). When analyzing grain yield, plots receiving an insecticide seed treatment increased yield compared to the fungicide-only treatment. Treatments containing a neonicotinoid in conjunction with a diamide seed treatment had yield increases compared to standalone neonicotinoid treatments and rice receiving no insecticide (Fig. 3). A trend can be observed in higher numerical grain yields when insecticide seed treatments contained a diamide. Overall grain yield decreases when diamides are not utilized compared to the treatments containing a combination (Fig. 4).

These data suggest that combining neonicotinoid and diamide seed treatments provides greater suppression of billbug when compared to single product seed treatments. Treatment combinations containing NipsIt + Fortenza and CruiserMaxx + Dermacor resulted in less tiller damage and greater grain yields than untreated plots or rice with CruiserMaxx alone. Damage tiller sampling showed some similarities between treatments when compared to yield. Damage tiller sampling timing needs to be refined because earlier sampling will allow undeveloped damage tillers to be accounted for. No reduction in blank heads was observed for any treatment. This suggests that blank headcounts alone do not correlate with grain yield. One possible explanation for the lack of differences is that tillers infested by billbug never developed enough to produce a blank head.

Practical Applications

Currently, there are very few options that provide any control of rice billbug. Options outside of insecticide seed treatments have not performed well and have not consistently provided control of yield protection from rice billbug. The only option that we have observed to provide control of rice billbug is the use of insecticide seed treatments, in particular combinations of neonicotinoid and diamide seed treatments. It is suggested that if growers are planting row rice, a diamide needs to be added to the seed to help protect against rice billbug damage.

Acknowledgments

We would like to thank the Arkansas Rice Promotion Board for funding this research through the Arkansas Rice Checkoff, as well as Stan Haigwood for the use of his land, and Arkansas Cooperative Extension Service County agents for their collaboration with this project.

Literature Cited

Felts, S.G., N.R. Bateman, G.M. Lorenz, B.C. Thrash, J.T. Hardke, A.J. Cato, T.L. Clayton, N.M. Taillon, J.K. McPherson, W.A. Plummer, L.D. McCullars, and W.J. Plummer. 2019. Evaluation of Insecticide Seed Treatment Options for Controlling Rice Billbug in Row Rice. *In*: R.J. Norman and K.A.K Moldenhauer (eds.). B.R. Wells Arkansas Rice Research Studies 2018. University of Arkansas Agricultural Experiment Station Research Series 659:165-167.

Hardke, J.T. and J.L. Chlapecka. 2019. Arkansas Furrow-Irrigated Rice Handbook. Introduction. University of Arkansas System Division of Agriculture Cooperative Extension Service. https://www.uaex.uada.edu/farm-ranch/crops-commercial-horticulture/rice/ArkansasFurrowIrrigatedRice-Handbook.pdf

Table 1. Trade names, rates, and insecticide class included in analysis.

Trade Name	Rate (oz/cwt)	Insecticide Class
CruiserMaxx Rice (CMR) (Thiamethoxam)	7 (oz/cwt)	Neonicotinoid
NipsIt Inside (NIP) (Clothianidin)	1.92 (oz/cwt)	Neonicotinoid
Dermacor (DMC) (Chlorantraniliprole)	5 (oz/cwt)	Diamide
Fortenza (FTZ) (Cyantraniliprole)	3.47 (oz/cwt)	Diamide
CruiserMaxx Rice + NipsIt Inside (CMR + NIP)	7 + 1.92 (oz/cwt)	Neonicotinoid + Neonicotinoid
CruiserMaxx Rice + Dermacor (CMR +DMC)	7 + 5 (oz/cwt)	Neonicotinoid + Diamide
CruiserMaxx Rice + Fortenza (CMR + FTZ)	7 + 3.47 (oz/cwt)	Neonicotinoid + Diamide
NipsIt Inside + Dermacor X-100 (NIP+DMC)	1.92 + 5 (oz/cwt)	Neonicotinoid + Diamide
NipsIt Inside + Fortenza (NIP + FTZ)	1.92 + 3.47 (oz/cwt)	Neonicotinoid + Diamide
Untreated	N/A	N/A

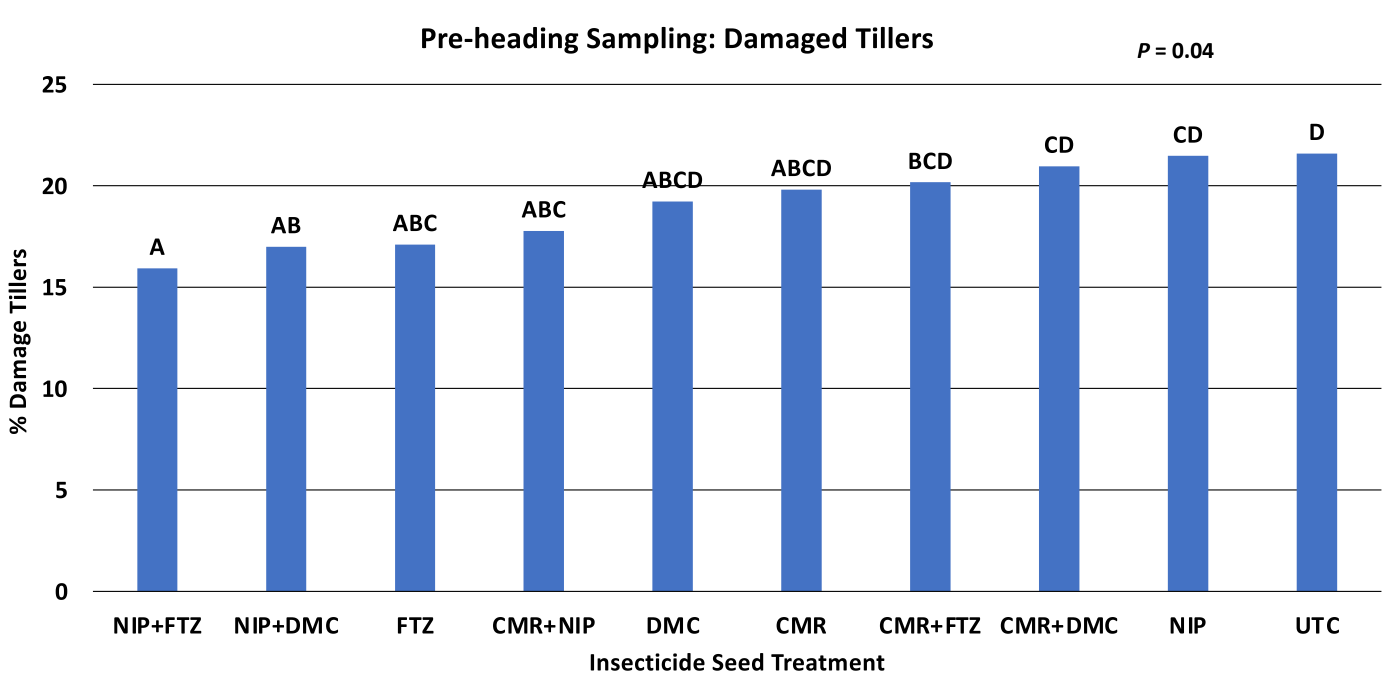

Fig. 1. Percent damaged tillers caused by rice billbug in furrow-irrigated rice for selected insecticide seed treatments, Jackson County, Ark., 2020–2021. Means followed by the same letter are not significantly different (α ≤ 0.05).

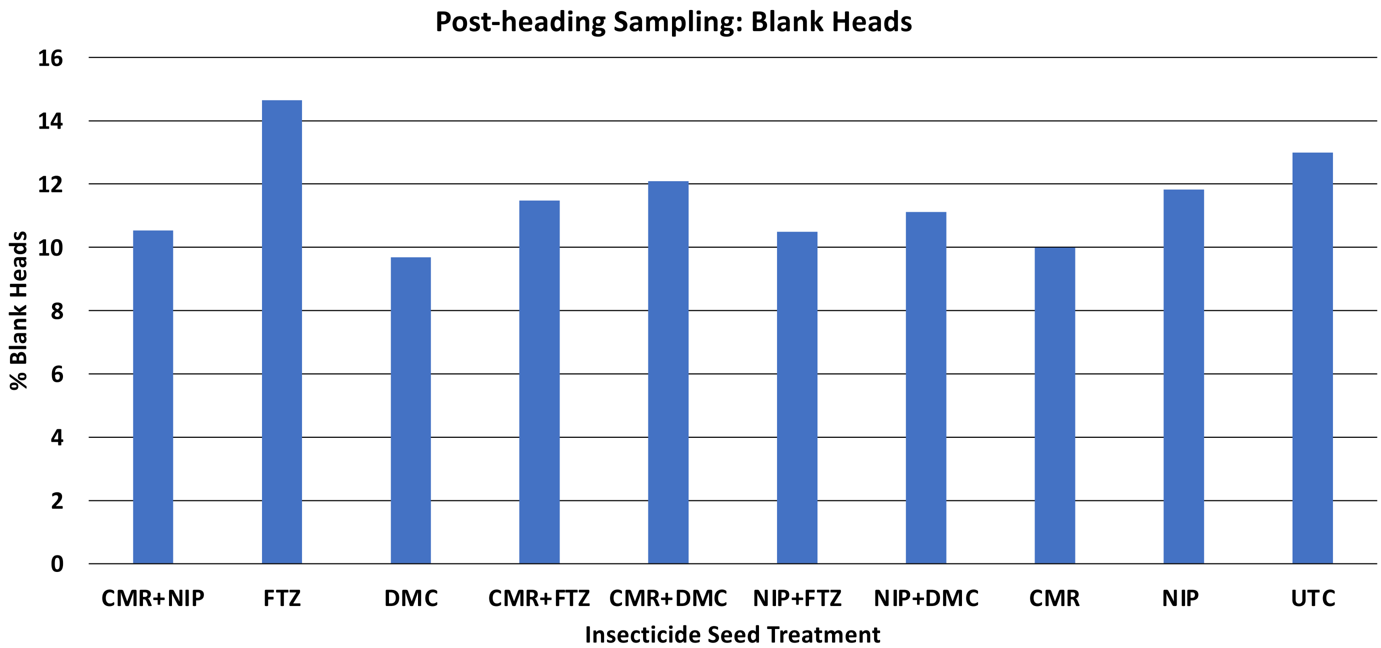

Fig. 2. Blank panicles caused by rice billbug feeding for selected insecticide seed treatments in furrow-irrigated rice, Jackson County, Ark., 2020–2021.

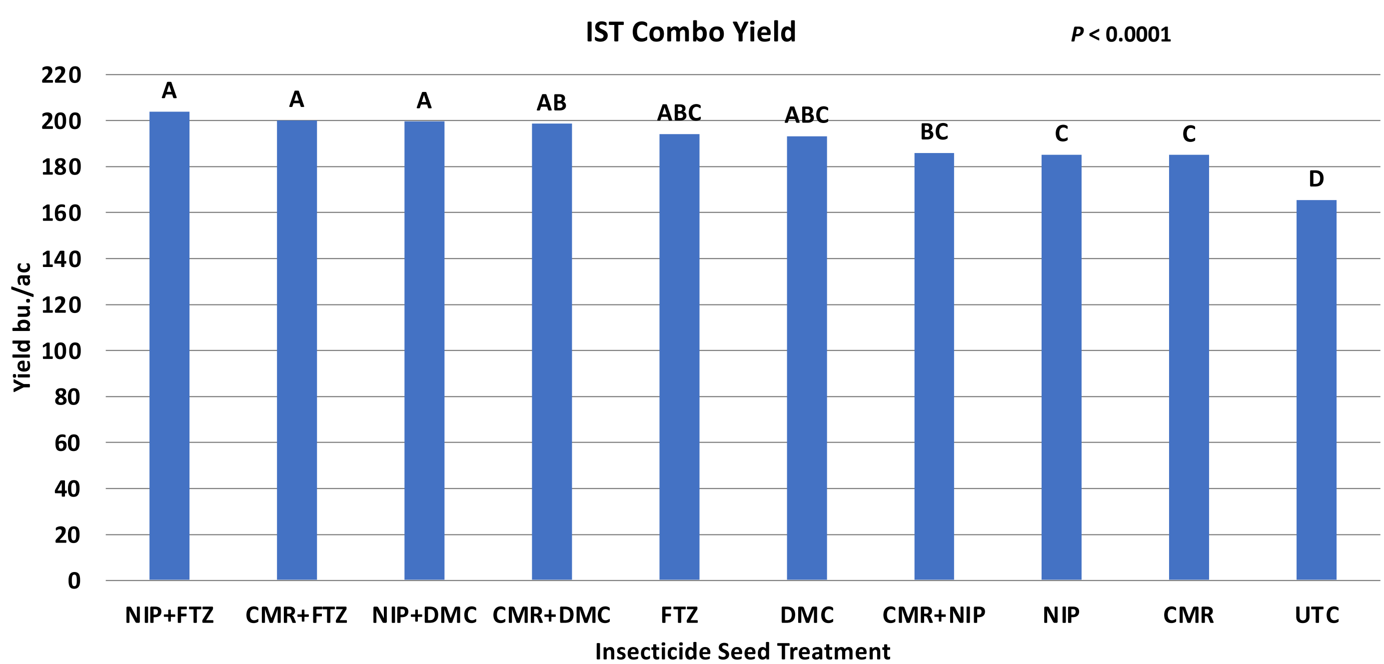

Fig. 3. Rice grain yield of selected insecticide seed treatments for control of rice billbug, Jackson County, Ark., 2020–2021. Means followed by the same letter are not significantly different (α ≤ 0.05).

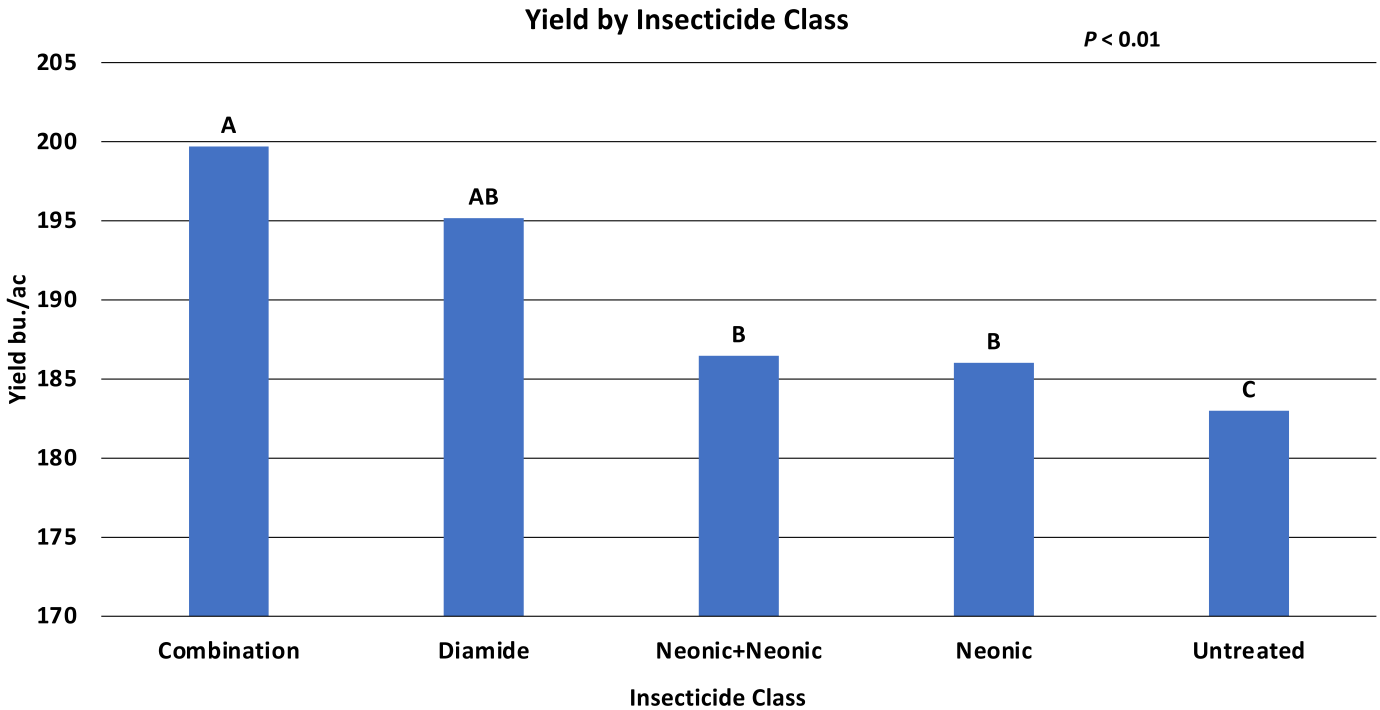

Fig. 4. Rice grain yield of insecticide seed treatment classes for control of rice billbug, Jackson County, Ark., 2020–2021. Means followed by the same letter are not significantly different (α ≤ 0.05).

Examining Pyrethroid Resistance in Rice Stink Bug in Arkansas

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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 insecticides 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 2019, 2020, and 2021. Populations of RSBs were collected in May, June, and July throughout the state in 2021. Lambda was applied to Petri dishes at five different rates: 0.46 oz/ac (0.25X), 0.93 oz/ac (0.5X), 1.82 oz/ac (1.0X), 3.72 oz/ac (2.0X), and 7.44 oz/ac (4.0X) and an untreated check for comparison. Over the 14 populations that were sampled, 65% mortality was observed for a 1X rate of lambda. A 2X rate resulted in 72% mortality, and the 4X rate achieved 74% mortality. These results indicate that pyrethroid insecticide resistance may become a problem in RSB in Arkansas, and further testing is needed to determine future management strategies.

Introduction

The rice stink bug (RSB), *Oebalus pugnax*, is the number one pest of heading rice in Arkansas. In recent growing seasons, approximately 50% of rice acres were treated for 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. If 2.5%-peck is exceeded, rice mills could potentially dock the grower. Pyrethroids make 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 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. Rice stink bug resistance to pyrethroids has not been documented in Arkansas; however, there have been reported problems with resistance in Texas and Louisiana (Miller et al., 2010; Blackman et al., 2015), and a lack of control was observed in Arkansas late in the season in 2019 and 2020 (Lorenz et al., 2019; Newkirk et al., 2020). The main objective of this study was to determine if there is a developing problem with pyrethroid insecticide resistance to rice stink bug in Arkansas.

Procedures

In 2021, 14 populations were collected throughout the state to conduct resistance assays. In May, 4 collections were made, while 5 collections were made in June and July. Approximately 450 RSBs were collected from each location. Collections were made using sweep nets in rice fields, wheat fields, and native grasses. Rice stink bugs 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 were soaked in sugar water for moisture. Rice stink bugs were transported to the laboratory at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center, Stuttgart, Arkansas. Lambda (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 gal/ac at 40 psi. 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

For the collections made in May, all treatments had greater mortality than the untreated check. 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, and each achieved greater than 80% mortality (Fig. 1). A similar trend was observed for June and July collec-

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tions. For the June collections, no differences were observed between the 1X, 2X, and 4X rates of Lambda for mortality of RSB, and 80% mortality was not achieved (Fig. 2). In July, the 1X, 2X, and 4X rates had higher mortality than the 0.25X and 0.5X rates, and 80% mortality was not reached (Fig. 3). Across all months, all treatments had increased mortality compared to the untreated check; however, no treatment achieved 100% mortality (Fig. 4).

Practical Applications

Assay results indicate that resistance/tolerance in rice stink bugs to Lambda may be a developing issue for Arkansas rice producers. May populations are the first generation of RSBs to come out of overwintering, which are typically weaker compared to June and July populations, having built up their fat bodies. May was the only month to achieve 80% mortality which is still two months prior to RSBs infesting rice. It is important to realize that these results are preliminary and that more work must be done before we can definitively tell whether a problem is developing. We plan to continue our assays to determine the extent of these resistance/tolerance issues. If pyrethroid resistance is developing, we will need to educate our growers and consultants on sustainable insecticide resistance management. Future research in 2022 will be conducted to continue monitoring resistant populations.

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.

Literature Cited

Lorenz, G.M., N. Joshi, N.R. Bateman, B.C. Thrash, N.M. Taillon, S.G. Felts, W.A. Plummer, W.J. Plummer, J.K. McPherson, C. Floyd, and C. Rice. 2020. Preliminary Observations of Potential Tolerance/Resistance to Pyrethroids in Rice Stink Bugs in Arkansas. *In*: K.A.K. Moldenhauer, B. Scott, and J. Hardke (eds.). B.R. Wells Arkansas Rice Research Studies. 2019. University of Arkansas Agricultural Research Station Research Series 667:116-119. Fayetteville.

Blackman, B., S. Lanka, N. Hummel, M. Way, and M. Stout. 2015. Comparison of the effects of neonicotinoids and pyrethroids against *Oebalus pugnax* (Hemiptera:Pentatomidae) in rice. Fla. Entomol. 98:18-26.

Miller, A., M. Way, J. Bernhardt, M. Stout and K. Tindall. 2010. Multi-state resistance monitoring of rice stink bug with a new and old insecticide. pp. 35-38. *In*: Proceedings of the Rice Technical Working Group. Editor M.E. Salassi. 207 pages. Biloxi, Miss.

Newkirk, T., N.R. Bateman, G.M. Lorenz, B.C. Thrash, S.G. Felts, N.M. Taillon, W.A. Plummer, J.P. Schafer, C.A. Floyd, A. Whitfield, Z. Murray, C. Rice, and T. Harris. 2021. Preliminary Observations of Potential Tolerance/Resistance to Pyrethroids in Rice Stink Bugs in Arkansas. *In*: J. Hardke, X. Sha, and N. Bateman (eds.). B.R. Wells Arkansas Rice Research Studies. 2020. University of Arkansas Agricultural Research Station Research Series 676:117-119. Fayetteville.

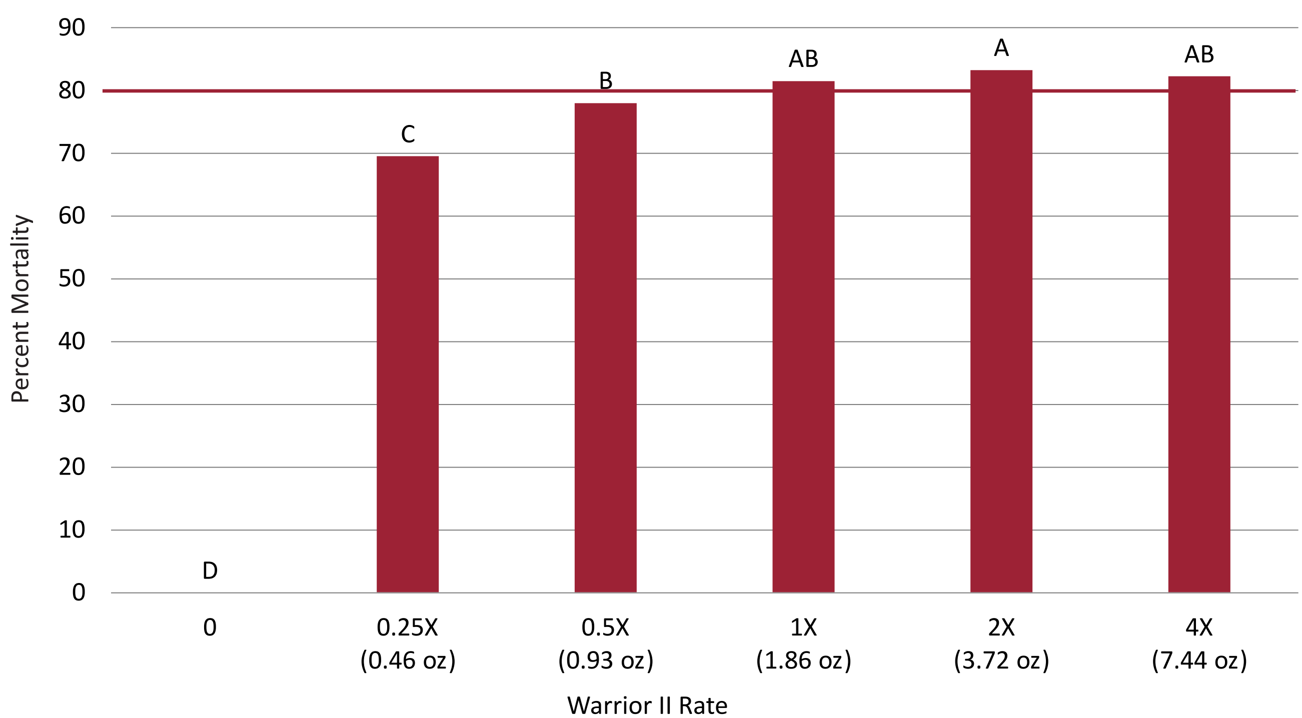

Fig. 1. Efficacy of Lambda for rice stink bug (RSB) at multiple rates 24 hours after exposure in May. The red line shows the percent mortality to be considered good control. Means followed by the same letter are not significantly different at an alpha level of 0.05.

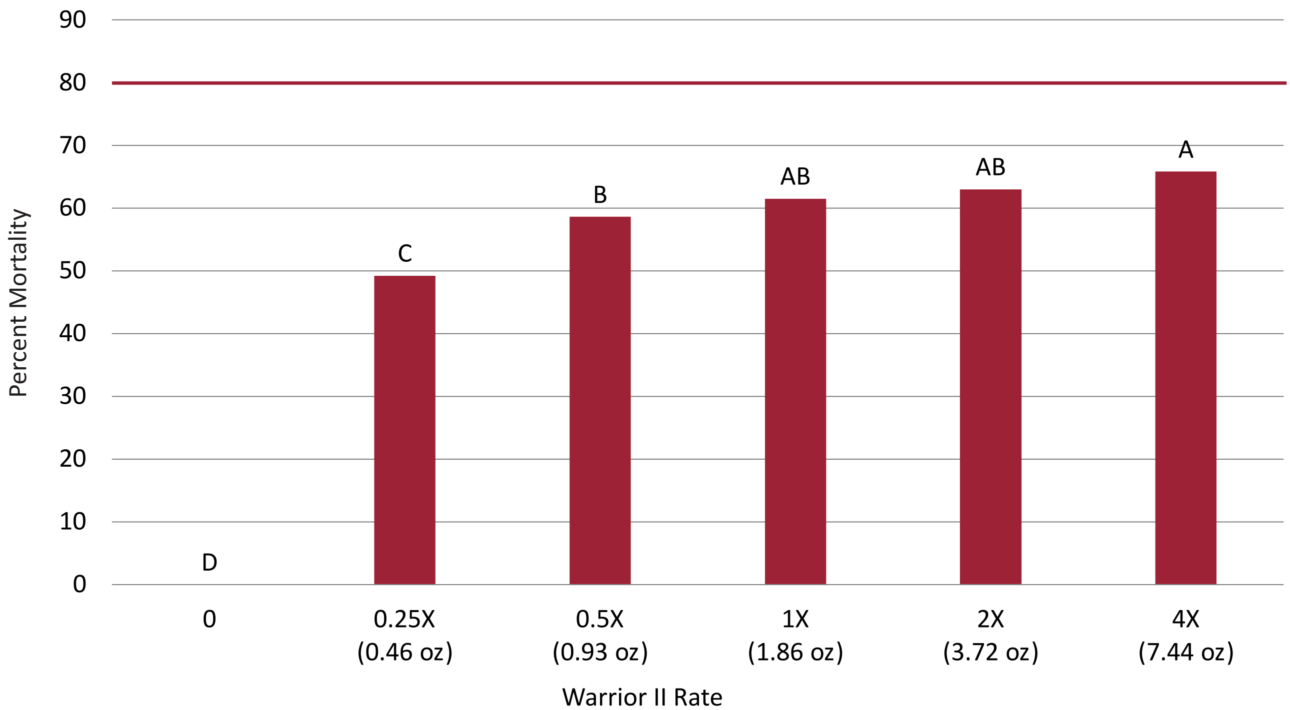

Fig. 2. Efficacy of Lambda for rice stink bug (RSB) at multiple rates 24 hours after exposure in June. The red line shows the percent mortality to be considered good control. Means followed by the same letter are not significantly different at an alpha level of 0.05.

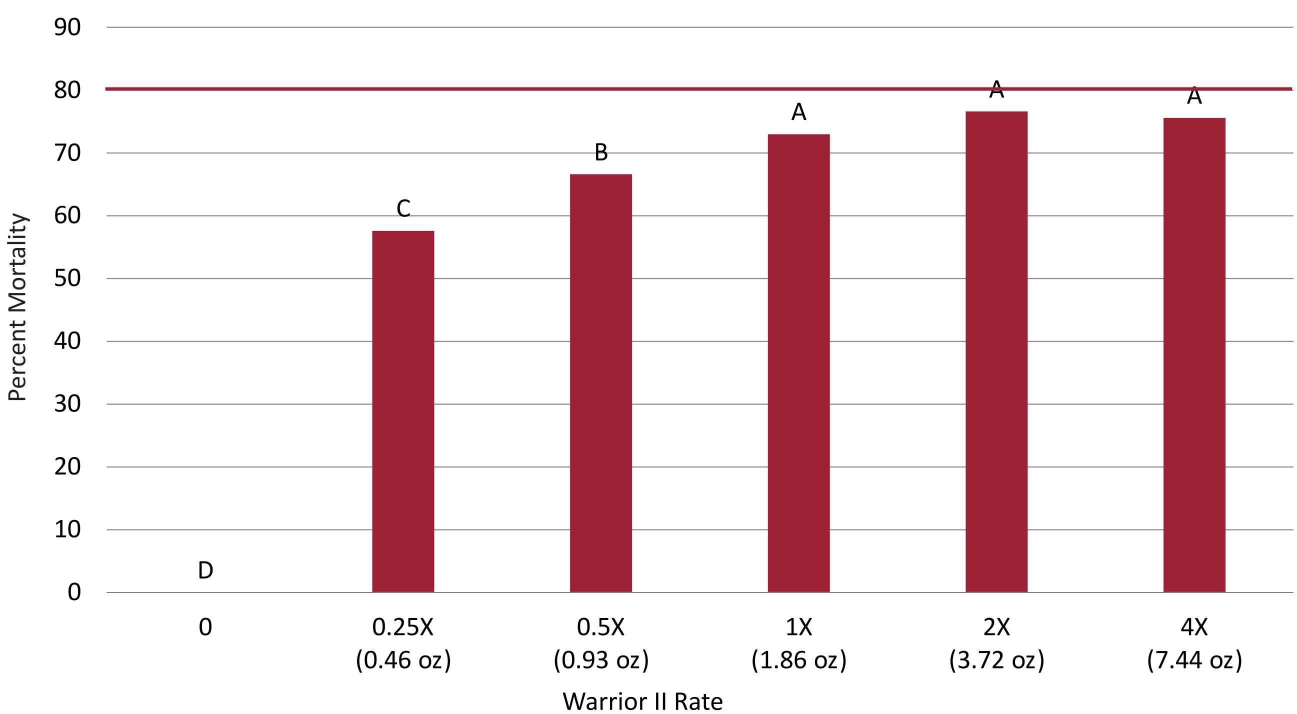

Fig. 3. Efficacy of Lambda for rice stink bug (RSB) at multiple rates 24 hours after exposure in July. The red line shows the percent mortality to be considered good control. Means followed by the same letter are not significantly different at an alpha level of 0.05.

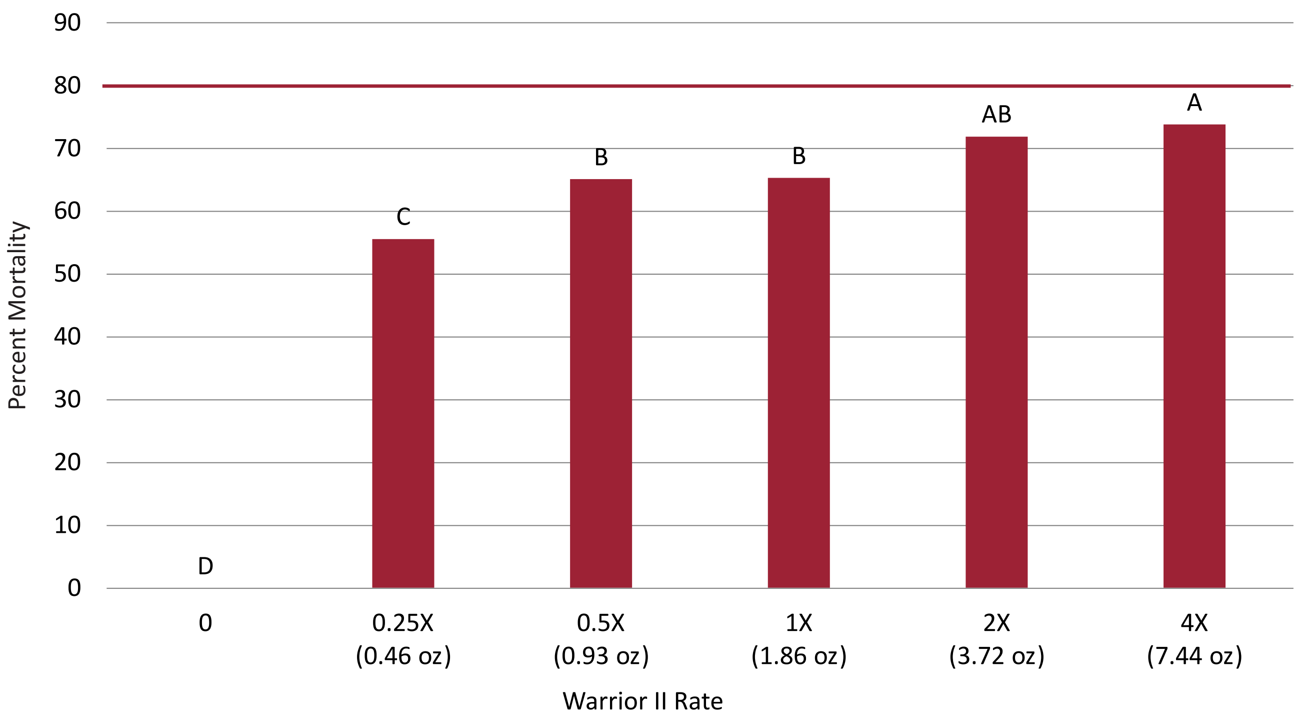

Fig. 4. Efficacy of Lambda for rice stink bug (RSB) at multiple rates 24 hours after exposure on average of 14 locations. The red line shows the percent mortality to be considered good control. Means followed by the same letter are not significantly different at an alpha level of 0.05.

Comparison of Multiple Insecticides for Efficacy and Residual Control of Rice Stink Bug in Arkansas, 2021

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Abstract

Rice stink bug (RSB) is a major pest of rice that feeds 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, providing adequate control at a 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 in preparation for resistance to lambda. Foliar efficacy field trials were performed in 2021 to compare insecticides for efficacy and residual control of rice stink bug. Sweep net samples were taken at 3, 7, 10, and 13 days after treatment (DAT) to monitor RSB efficacy. Excluding the pyrethroids, all other insecticides provided adequate control of nymphs.

Introduction

Rice stink bug (RSB), *Oebalus pugnax*, 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 application per year for RSB; but in very early or very late heading rice, multiple applications may be warranted to keep RSB densities below threshold. For weeks 1 and 2 after 75% heading, our threshold is 5 RSB per 10 sweeps. For weeks 3 and 4 after 75% heading, our threshold is raised to 10 RSB per 10 sweeps. Limited insecticide options are currently available for RSB control (Lorenz et al., 2018). Lambda-cyhalothrin (Warrior II and generics), a pyrethroid, has been the current standard for RSB control for the past 15 years. In contrast to the 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 not rotating chemistry 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 at three locations, Arkansas County, Jefferson County, and Prairie County, Arkansas, in 2021, to compare insecticides for efficacy and residual control of RSB. Locations were selected when RSB densities exceeded threshold. Applications of insecticides were made with a backpack sprayer and a 12-ft hand boom (10 gal/ac), and plot size was 12 ft by 35 ft. Treatments were arranged in a randomized complete block design with four replications (Table 1). Sweep net sampling was performed at 3, 7, 10, and 13 DAT by conducting 10 sets of 10 sweeps to monitor RSB populations. Sampling was conducted until plots reached 60% hard dough.

Results and Discussion

At 3 and 7 DAT, all insecticides reduced nymph numbers below threshold; however, Tenchu and both rates of Endigo ZCX reduced nymph numbers lower than all other treatments (Figs. 1 and 2). At 10 DAT, nymph populations begin to increase, but all applications of insecticides successfully suppressed nymph numbers below the untreated control. Both rates of Endigo ZCX, Tenchu, as well as Carbaryl successfully reduced total RSB populations below threshold (Fig. 3). At 13 DAT, besides Tenchu and both rates of Endigo ZCX, all other insecticides failed to keep all RSB populations below threshold. All other insecticide applications failed to significantly reduce total RSB populations compared to rice receiving no insecticide (Fig. 4). Total RSB populations increased due to migrating adults entering the plots. 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.

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 Tenchu is recommended. With the growing concerns of pyrethroid resistance/tolerance of RSB,

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new insecticide options should be evaluated. New products, such as Endigo ZCX, are still in the works of receiving an EPA label, and Tenchu is costly for growers but may become the only option in the future.

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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 to use their land.

Literature Cited

Lorenz, G., N. Bateman, J. Hardke, and A. Cato. 2018. Insect management in rice. *In*: J.T. Hardke (ed.). Arkansas Rice Production Handbook. University of Arkansas System Division of Agriculture Cooperative Extension Service. MP192 pp. 139. Available at: https://www.uaex.uada.edu/publications/pdf/MP192/MP192.pdf

Swanson, M.C. and L.D. Newsom. 1962. Effect of infestation by the rice stink bug, *Oebalus pugnax*, on yield and quality in rice. J. Econ. Entomol. 55(6):877-879.

Way, M.O. and K.V. Tindall. 2009. Abstracts and Proceedings: Resistance Monitoring in Rice Stink Bug and Other Rice IPM Updates. Proceedings of 21st Ann. Texas Plant Protection Conference: Applications of Agric. Technology and Management for Changing Times, Brazos Center, Bryan, Texas. Dec 2-3, pg 23.

Table 1. Insecticide names, rates, and insecticide class included in analysis.

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

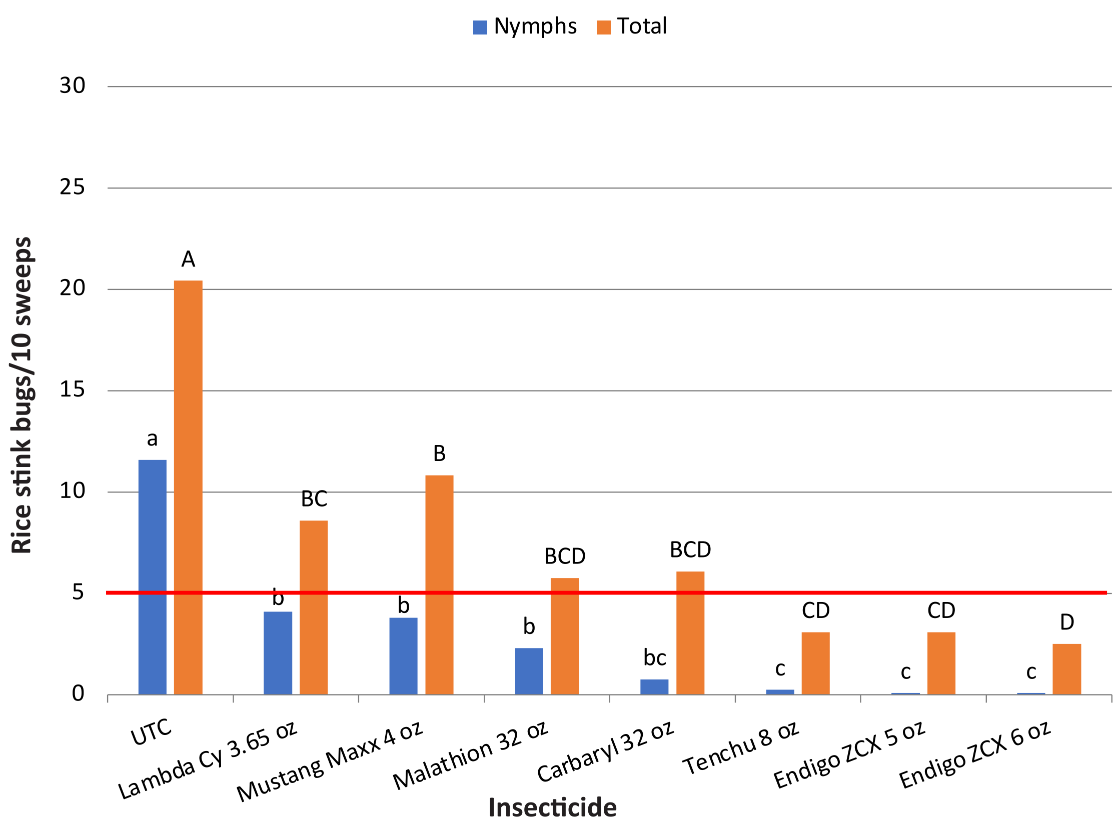

Fig. 1. Efficacy trials at 3 days after treatment comparing labeled insecticides for control of rice stink bug. The red line is set at 5, representing the threshold. Means followed by the same letter are not significantly different at an alpha level of 0.05.

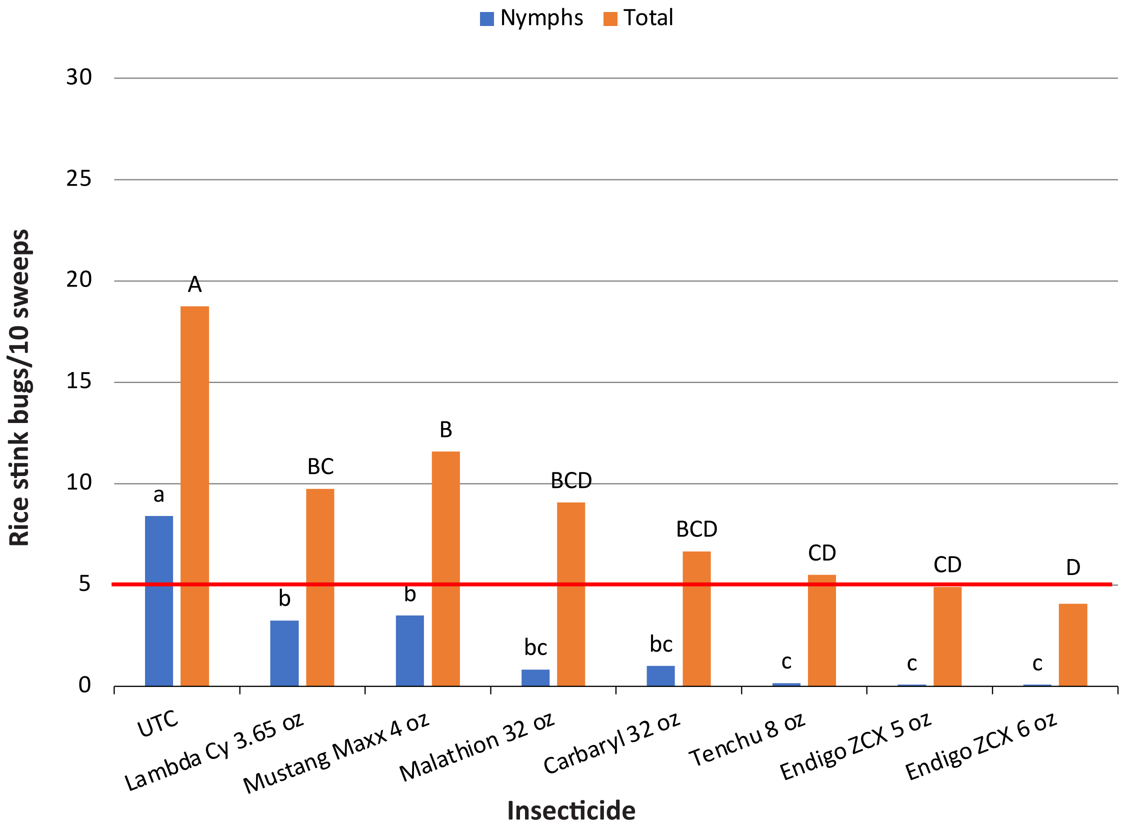

Fig. 2. Efficacy trials at 7 days after treatment comparing labeled insecticides for control of rice stink bug. The red line is set at 5, representing the threshold. Means followed by the same letter are not significantly different at an alpha level of 0.05.

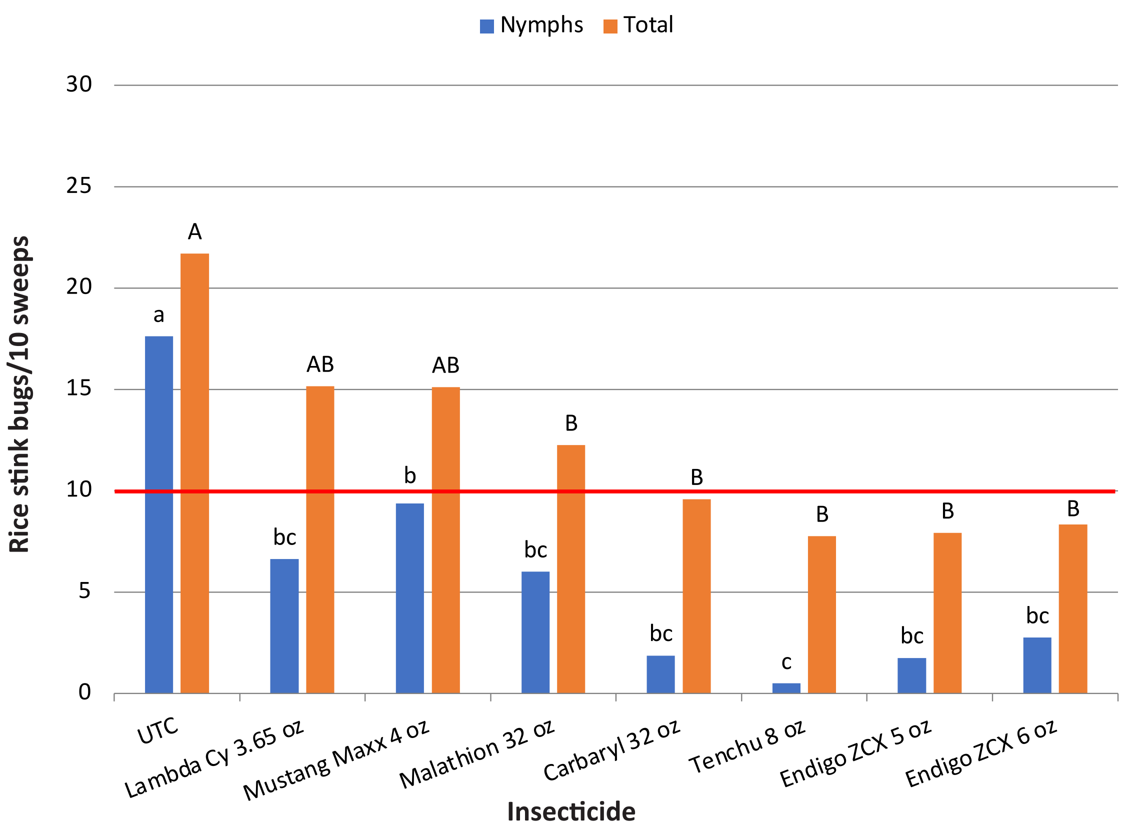

Fig. 3. Efficacy trials at 10 days after treatment comparing labeled insecticides for control of rice stink bug. The red line is set at 10, representing the threshold. Means followed by the same letter are not significantly different at an alpha level of 0.05.

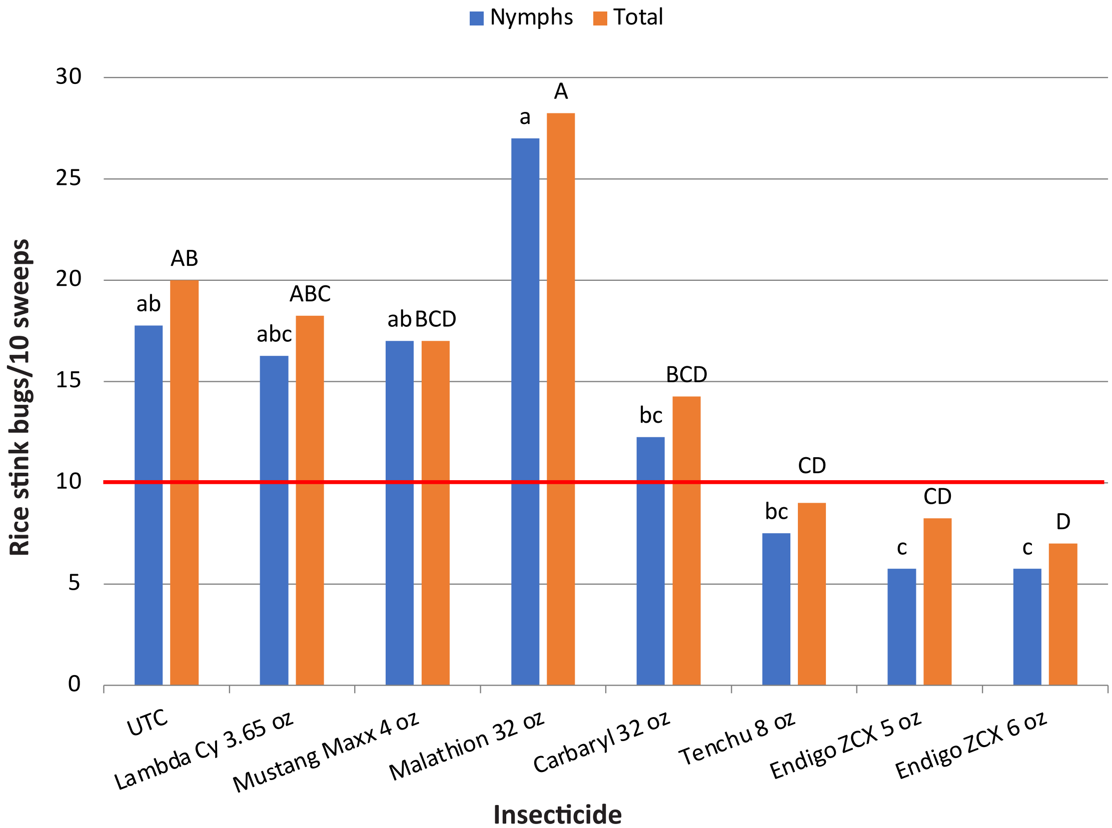

Fig. 4. Efficacy trials at 13 days after treatment comparing labeled insecticides for control of rice stink bug. The red line is set at 10, representing the threshold. Means followed by the same letter are not significantly different at an alpha level of 0.05.

Efficacy of Selected Insecticides for Control of Fall Armyworm in Rice

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Abstract

In 2021, fall armyworm (FAW) impacted more rice acres than any other year in the past several decades. On top of this were the widespread failures with pyrethroid insecticides, including lambda-cyhalothrin. Two trials were initiated on grower fields in Arkansas County, Ark., to evaluate multiple insecticides for control of FAW. Fall armyworm density was recorded using a sweepnet, and percent defoliation was recorded. Results indicate Vantacor provided the greatest control of FAW, followed by Intrepid at 3 and 5 oz/ac. Lambda-cyhalothrin provided 56% and 90% control in locations 1 and 2, respectively. These results match the variable control observed by rice growers in Arkansas.

Introduction

Fall armyworm (FAW) is an occasional pest of rice in Arkansas, typically causing limited damage to relatively few acres (Lorenz et al., 2018). However in 2021, FAW was more severe in terms of affected rice acres, as well as the amount of damage caused, than has been observed in over 30 years in Arkansas (Lorenz, pers. comm.). Additionally, many growers were reporting poor control or failures with pyrethroid insecticides such as lambda-cyhalothrin. In situations such as this, where no other alternatives to control a pest are available, a section 18 crisis exemption request can be made to the EPA, which allows growers to legally apply another insecticide for control of the target pest. In order to apply for a section 18 crisis exemption request, data must be provided to the EPA showing failure of the currently labeled insecticide, as well as the insecticide being requested in the exemption. The objective of these tests was to evaluate if lambda-cyhalothrin (Lambda-cy) was continuing to provide an acceptable level of control of FAW in rice and to evaluate several other products for control of FAW.

Procedures

In 2021 trials were established in two separate grower fields in Arkansas County, Arkansas. Plot size was 12.5 ft × 30 ft with 4 replications. Insecticides were applied with a 12.5 ft wide CO_2-powered backpack sprayer using TXVS-4 hollowcone nozzles, delivering 10 gal/ac. At location 1, treatments were applied on 20 Aug. and sampled 4 and 7 days after treatment (DAT). At location 2, treatments were applied on 27 Aug. and sampled 4 DAT. Fall armyworm densities were estimated by taking 10 sweeps per plot with a 15-in. sweepnet and counting the number of live larvae within the net. Estimated percent defoliation was also recorded for each plot. Treatments and rates in oz/ac are displayed in Figs. 1–6.

Results and Discussion

At location 1, 4 and 7 DAT, Vantacor provided the greatest control of FAW, followed by both rates of Intrepid (Figs. 1 and 2). Lambda-Cy provided poor (56%) control of FAW at this location. Percent defoliation was lowest in Vantacor and both rates of Intrepid at both sample dates as well (Figs. 3 and 4). At location 2, 4 DAT, Vantacor provided the greatest control of FAW, followed by both rates of Intrepid (Fig. 5). Vantacor and Intrepid also had the lowest amount of defoliation at this location (Fig. 6). Lambda-cy provided good (90%) control at this location.

Lambda-cyhalothrin has historically been the most used insecticide for control of fall armyworm in rice. With insecticides, 80% control is generally considered acceptable, but as these results confirm, control was poor in some locations. Because of this, a section 18 crisis exemption for Intrepid 2F (methoxyfenozide) was requested from the EPA, and approval was received on 28 July. The section 18 allowed growers to legally apply Intrepid 2F for control of FAW on rice. The reason Intrepid was selected for the section 18 as opposed to other insecticides is that it was already approved in California for control of true and yellow stripe armyworms. This insecticide is considered "reduced risk" due to its low toxicity to off-target organisms, as well as its relatively low cost to growers. The results from these trials mimic the variable control that was commonly reported in 2021 and is typical to reports prior to widespread insecticide resistance.

Practical Applications

Pyrethroid insecticides have been our standard for fall armyworm control in rice up until 2021. These trials document their poor performance and also provide data on other insecticides that could be of potential use, upon approval of a section 18, should an outbreak happen again.

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Acknowledgments

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Literature Cited

Lorenz, G., N. Bateman, J. Hardke, and A. Cato. 2018. Insect Management in Rice. *In*: Arkansas Rice Production Handbook. University of Arkansas System Division of Agriculture Cooperative Extension Service. MP192 pp. 139-162. Available at: www.uaex.uada.edu/publications/pdf/mp192/chapter-12.pdf

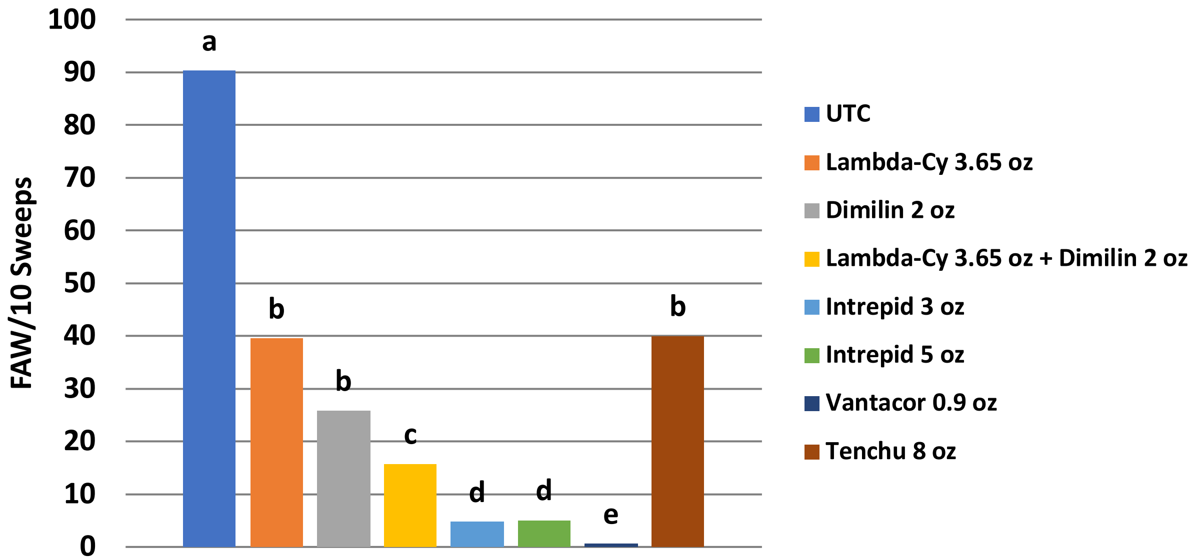

Fig. 1. Fall armyworm (FAW) control 4 days after treatment with selected insecticides, Arkansas County, Ark., Location 1, 2021. UTC = untreated control. Means followed by the same letter are not significantly different (α = 0.1).

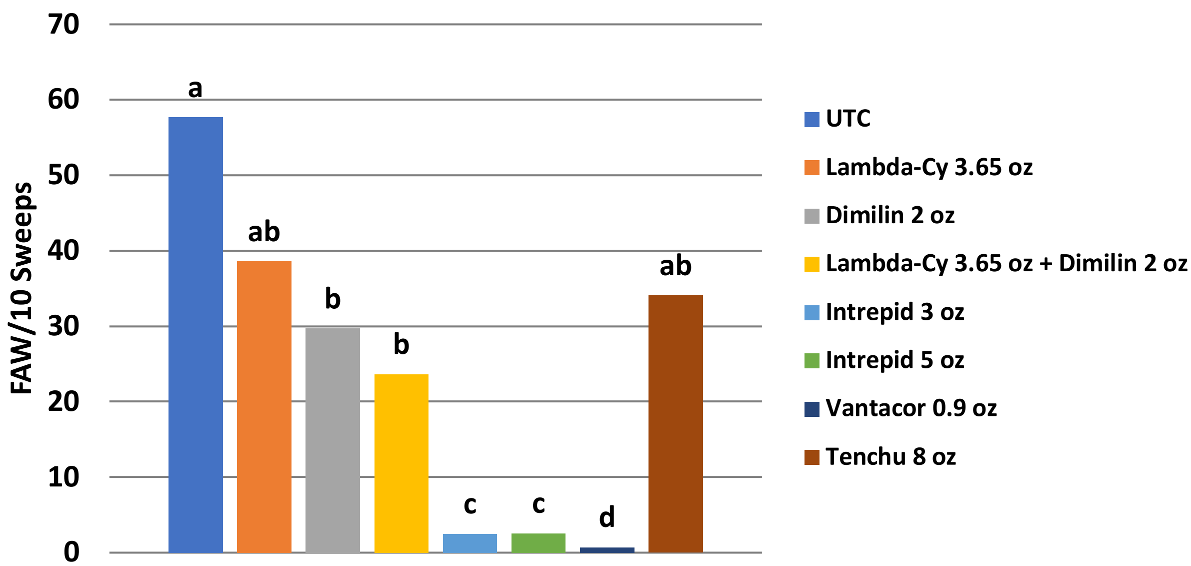

Fig. 2. Fall armyworm (FAW) control 7 days after treatment with selected insecticides, Arkansas County, Ark., Location 1, 2021. UTC = untreated control. Means followed by the same letter are not significantly different (α = 0.1).

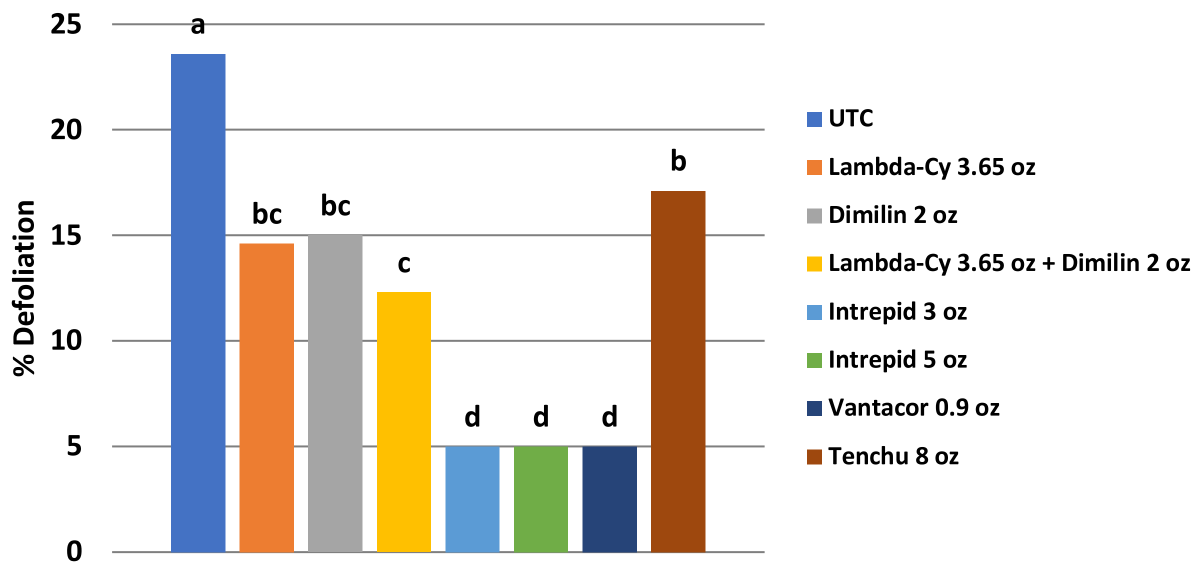

Fig. 3. Percent defoliation from fall armyworm (FAW) 4 days after treatment with selected insecticides, Arkansas County, Ark., Location 1, 2021. UTC = untreated control. Means followed by the same letter are not significantly different (α = 0.1).

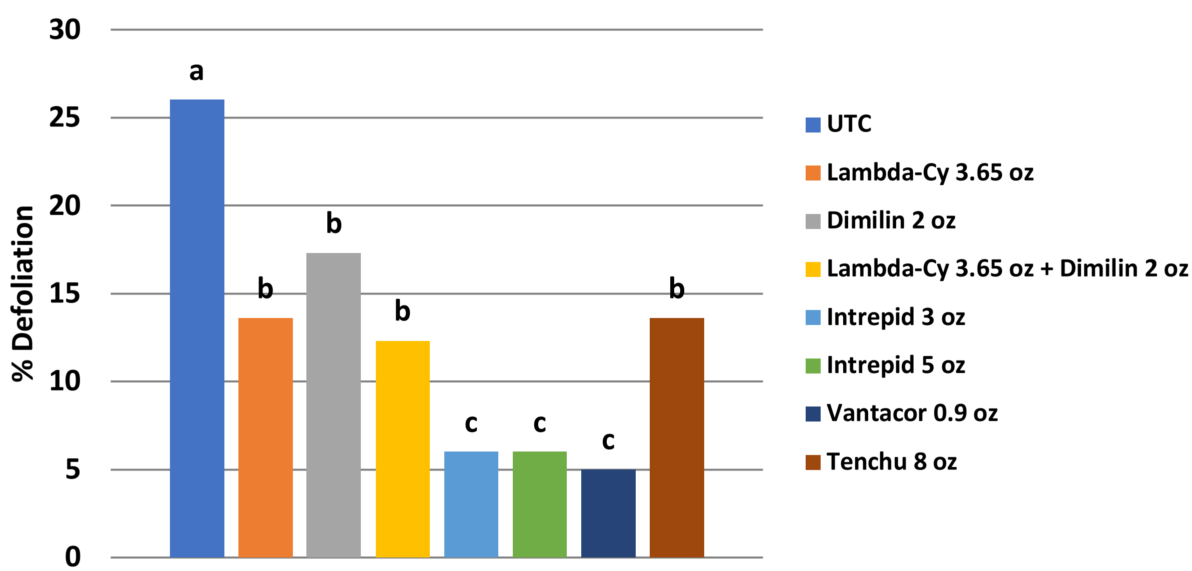

Fig. 4. Percent defoliation from fall armyworm (FAW) 7 days after treatment with selected insecticides, Arkansas County, Ark., Location 1, 2021. UTC = untreated control. Means followed by the same letter are not significantly different (α = 0.1).

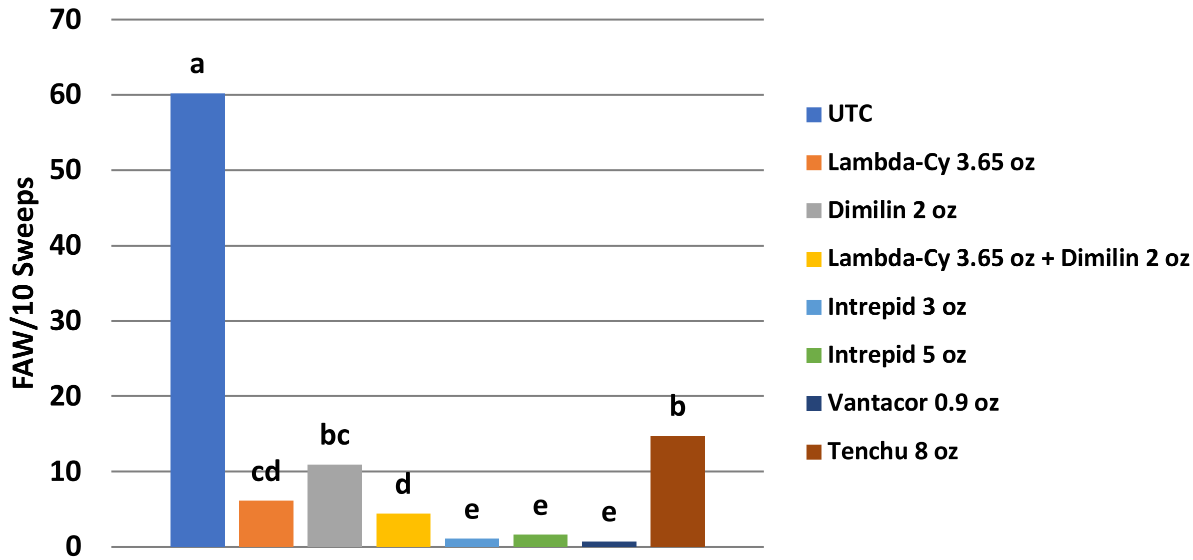

Fig. 5. Fall armyworm (FAW) control 4 days after treatment with selected insecticides, Arkansas County, Ark., Location 2, 2021. UTC = untreated control. Means followed by the same letter are not significantly different (α = 0.1).

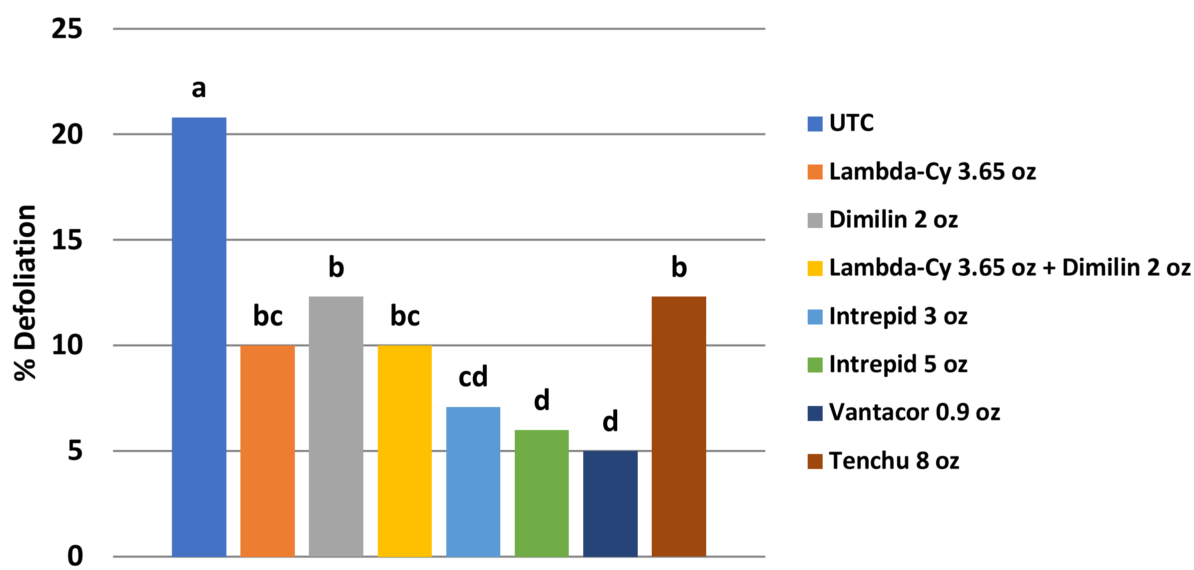

Fig. 6. Percent defoliation from fall armyworm (FAW) 4 days after treatment with selected insecticides, Arkansas County, Ark., Location 2, 2021. UTC = untreated control. Means followed by the same letter are not significantly different (α = 0.1).

What is the Impact of Dicamba When Applied on Early-Season Rice?

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Abstract

Dicamba is a herbicide currently used in Arkansas for broadleaf weed control in Xtend® and XtendFlex® cotton, soybean, corn, grain sorghum, and non-crop systems but is not labeled for use in rice. If a safe application time and rate can be determined for rice, dicamba could serve as an additional broadleaf weed control option. A field experiment focused on crop safety was conducted in 2021, near Stuttgart, Arkansas, at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center to evaluate the possibility of dicamba for use as an early season broadleaf material in rice. The experiment consisted of 2 factors: herbicide rate and application timing. Dicamba was applied in the form of Clarity® at 0.5 lb ae/ac (1x) and 1 lb ae/ac (2x) at 3 separate application timings [preemergence (PRE), 1-leaf, and 5-leaf growth stage]. Rice injury 2 weeks after the PRE application was 71% and 91% at a 1 and 2x rate, respectively. Applications made after PRE had less injury, as evident by 39% and 48% injury 2 weeks after the 1-leaf rice stage application at a 1 and 2x rate, respectively. The trend continues with the 5-leaf rice stage application, where the injury for a 1 and 2x rate was 8% and 12%, respectively. At 4 weeks after flood initiation, rice recovered to ≤5% injury, except for the PRE application at a 2x rate (33%). Based on these results, the severity of injury observed from early-season dicamba applications to rice would outweigh any benefits of broadleaf weed control.

Introduction

Dicamba is a Weed Science Society of America (WSSA) Group 4 synthetic auxin herbicide (WSSA, 2021) widely used in Arkansas as a burndown and for broadleaf weed control, specifically Palmer amaranth (*Palmeri amaranthus*, S. Watson), in cotton (*Gossypium hirsutum*, L.) and soybean (*Glycine max*, L.) production systems. Additionally, dicamba can be used for broadleaf weed control in many cereal crops but is not labeled for use in rice (*Oryza sativa*, L.) (Anonymous, 2010). Traditionally, Palmer amaranth is not a concern in conventional rice systems but is becoming an issue as furrow-irrigated rice (FIR) acreage continues to increase across the state (Barber et al., 2020). In a FIR system, the lack of a continuous flood and limited pre- and postemergence herbicide options provides additional broadleaf weed control challenges for producers. In rice, Palmer amaranth is resistant to acetolactate synthase, microtubule-, and protoporphyrinogen oxidase-inhibiting herbicides; however, there are additional modes of action to which Palmer amaranth is resistant in other cropping systems (Heap, 2022).

The broadleaf weeds hemp sesbania [*Sesbania herbacea*, (P. Mill.) McVaugh], spreading dayflower (*Commelina diffusa*, Burm. F.), northern jointvetch [*Aeschynomene virginica*, (L.) Britton, Sterns & Poggenb.], eclipta [*Eclipta prostrata*, (L.) L.], and Pennslyvania smartweed (*Polyginum pensylvanicum*, L.) are problematic in traditional flooded rice production (CES, 2021; Smith, 1988). Limited chemical control options combined with potentially herbicide-resistant broadleaf weeds in rice highlight the need for additional herbicides for weed control.

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, to determine the effects of dicamba rates and application timings on rice. The experiment was designed to determine if there is an optimal time to apply dicamba safely in rice. An imidazolinone-resistant cultivar (RT7321 FP) was drill-seeded at 11 seeds per ft, and plot dimensions were 6 ft wide by 17 ft long. The trial was irrigated by using flooded rice methods standard in Arkansas. No additional herbicide control methods were used in the trial. The trial was designed as a randomized complete block design with 2 factors (herbicide rate and application timing) with 4 replications. Dicamba was applied using the Clarity® formulation at 0.5 lb ae/ac (1x) and 1 lb ae/ac (2x). Each rate of dicamba was applied to rice at the preemergence (PRE), 1-leaf, and 5-leaf rice growth stages. All applications were made at 3 mph with a CO_2-pressurized backpack sprayer using AIXR110015 nozzles calibrated to deliver 15 gal/ac. Visual estimates of injury ratings were recorded at 1, 2, 3, and 4 weeks after treatment (WAT), with an additional rating at 4 weeks after flooding (WAF). Injury was rated on a scale from 0% to 100%, with 0% being no injury compared to the nontreated control and 100% being plant mortality. 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.

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Results and Discussion

An interaction occurred between herbicide rate and application timing 2 WAT and 3 to 4 WAT. At 2 WAT, the treatments resulted in 71%, 39%, and 8% injury when applied at a 1x rate at PRE, 1-leaf rice, and 5-leaf rice, respectively (Table 1). If dicamba became a labeled herbicide in rice, applications would be recommended at the 5-leaf growth stage to minimize rice injury. However, the application of dicamba would need to be applied before the plant enters the late boot growth stage, as we know dicamba applied to reproductive rice reduces grain yield (Castner et al., 2020). A 2x rate of dicamba 2 WAT resulted in 91%, 48%, and 12% injury at PRE, 1-leaf rice, and 5-leaf rice, respectively (Table 1). The injury observed after the PRE application was in the form of reduced stand.

Again, at 3 to 4 WAT, an interaction occurred between the herbicide rate and application timing. At a 1x rate, injury averaged by herbicide rate and application timing resulted in 66%, 32%, and 3% injury at PRE, 1-leaf rice, and 5-leaf rice, respectively. Injury 3 to 4 WAT averaged by herbicide rate and timing resulted in 76%, 57%, and 3% injury when a 2x rate of dicamba was applied at PRE, 1-leaf rice, and 5-leaf rice, respectively. At 3-4 WAT, the injury observed was significantly lower for the 5-leaf growth stage application compared to other application timings, supporting the statement that the 5-leaf growth stage of rice would be the best time to apply dicamba to mitigate rice injury based on this study. The injury ratings continued to decrease as the growing season progressed, evident by the ratings observed 4 weeks after flooding. At 4 WAF, injury was ≤5% for all applications, except for the 2x rate applied as a PRE (Table 1).

Practical Applications

Dicamba should not be applied to rice for weed control because the herbicide is not labeled in-crop for rice, and the risk of injury for applying dicamba to rice outweighs all advantages that could be gained by additional weed control. Although rice appeared to recover following flood initiation visually, severe penalties to yield could have occurred. Yield was not collected in this trial due to lodging caused by weedy rice. It is not recommended that growers apply a burndown tank mixture containing dicamba to a field planted with rice, as this can cause reduced stands.

Acknowledgments

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Literature Cited

Anonymous. 2010. Clarity product label. BASF Publication No. NVA 2010-04-065-0154. Research Triangle Park, NC: BASF. 22 pp.

Barber, L.T., T.R. Butts, and J.K. Norsworthy. 2020. Weed Management. Arkansas Furrow-Irrigated Rice Handbook. University of Arkansas System Division of Agriculture. 2020:18-20.

Castner, M.C., J.K. Norsworthy, J.A. Patterson, T. Butts, and O.W. France. 2020. Evaluation of Dicamba Exposure on Reproductive Rice. *In*: K.A.K. Moldenhauer, B. Scott, and J. Hardke (eds.) B.R. Wells Arkansas Rice Research Studies 2019. University of Arkansas Agricultural Experiment Station Research Series 667:125-127.

CES. 2021. *In*: J.T. Hardke (ed). Arkansas Rice Production Handbook. University of Arkansas System Division of Agriculture's Arkansas Cooperative Extension Service, MP 192, Little Rock, Ark. 51-61.

Heap., I. 2022. International Herbicide-Resistant Weed Database. Accessed 7 January 2022. Available at http://www.weedscience.org/Pages/Species.aspx

Smith., R.J. 1988. Weed Thresholds in Southern U.S. Rice, *Oryza sativa*. Weed Technol 2:232-241.

WSSA. Weed Science Society of America. 2021. Herbicide Site of Action (SOA) Classification List. Accessed 7 January 2022. https://wssa.net/wssa/weed/herbicides/

Table 1. Rice injury 2 weeks after treatment, 3 to 4 weeks after treatment, and 4 weeks after flooding for the interaction between herbicide rates and application timing from 2021, near Stuttgart, Arkansas.

Timing	Rate		Injury 2 WAT	Injury 3–4 WAT	Injury 4 WAF
	(lb ae/ac)		----------	(%)	----------
Preemergence	0.5	1x	71 b[†]	66 ab	0 b
	1	2x	91 a	76 a	33 a
1-leaf	0.5	1x	39 c	32 c	0 c
	1	2x	48 c	57 b	5 b
5-leaf	0.5	1x	8 d	3 d	3 b
	1	2x	12 d	3 d	3 b

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

Evaluation of Rice Tolerance with Warrant and Fenclorim under Cool, Wet Growing Conditions

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Abstract

Chloroacetamide herbicides are unavailable for U.S. rice production, likely due to the high risk of injury and variability associated with an early application and activation timings. Environmental conditions can induce severe injury and stand loss at early application timings. Previous research from the University of Arkansas System Division of Agriculture has demonstrated the efficacy of Warrant® [acetochlor, Weed Science Society of America (WSSA) Group 15] to control problematic weeds in rice and a fenclorim seed treatment to reduce rice injury under typical drill-seeded rice-growing conditions but not under cool, saturated conditions. Therefore, two growth chamber experiments were initiated to evaluate rice tolerance with a 12-hour photoperiod, a night temperature of 55 °F, and a 75 °F day temperature. The experiment was designed as a three-factor factorial: with or without fenclorim (2.5 lb/1000 lb of seed), with or without Warrant (2.5 pt/ac) applied delayed-preemergence (DPRE), and a 0.25-in. or 1-in. planting depth. Rice shoots, heights, and visual injury estimates were recorded weekly until termination and biomass collection 30 days after emergence (DAE). The fenclorim seed treatment alone at 7 and 14 DAE caused a reduction in height by delaying emergence relative to the nontreated control, but height recovered by 21 DAE. Warrant alone caused injury ranging from 15% to 60%, while the fenclorim seed treatment reduced injury to rice from Warrant ranging from 0% to 20%. The deeper planting depth also improved tolerance to Warrant alone for all evaluations but did not provide commercial tolerance. Relative to the nontreated control, fenclorim alone improved aboveground rice biomass, while fenclorim and Warrant were comparable to the nontreated control and greater than Warrant alone. After 14 DAE, the fenclorim seed treatment enhanced crop tolerance to Warrant for all evaluations. Based on the results of this study, Warrant applied DPRE at 2.5 pt/ac with a fenclorim seed treatment should provide commercial tolerance in drill-seeded rice.

Introduction

Previous research has demonstrated the utility of Warrant® to control problematic weeds in rice (*Oryza sativa*, L.) (Fogleman et al., 2019; Godwin et al., 2018; Norsworthy et al., 2019). However, very-long-chain fatty acid-elongase inhibitors (WSSA Group 15) are not labeled for use in U.S. rice production. Pretilachlor, a Group 15 chloroacetamide similar to acetochlor, has been labeled in Asian rice production for several years when used in conjunction with a herbicide safener fenclorim (Chen et al., 2013; Quadranti and Ebner, 1983). Fenclorim reduces chloroacetamide injury by upregulating metabolites and reducing herbicide uptake (Scarponi et al., 2005).

The University of Arkansas System Division of Agriculture (UADA) has developed a fenclorim seed treatment to reduce rice injury caused by Warrant (Avent et al., 2020, 2021). Currently, the fenclorim seed treatment has provided adequate crop tolerance to Warrant up to 3 pt/ac as early as the delayed-preemergence (DPRE) timing under typical drill-seeded rice-growing conditions. However, the UADA has yet to demonstrate adequate tolerance under adverse growing conditions such as saturated soils and cool temperatures, which exacerbate residual herbicide injury. Therefore, trials were conducted to determine the effectiveness of a fenclorim seed treatment to mitigate rice injury caused by Warrant under less-than-optimum growing conditions.

Procedures

Two growth chamber experiments were initiated at the Milo J. Shult Agricultural Research and Extension Center in Fayetteville, Arkansas, in 2021. Both growth chambers were set to provide a 12-h photoperiod with day and nighttime temperatures of 75 °F and 55 °F, respectively. Prior to the trials, soil analysis was conducted at the University of Arkansas System Division of Agriculture's Diagnostic Lab in Fayetteville, Arkansas using loss on ignition for organic matter and the hydrometer method for texture resulting in a 6.4 pH and 2.3, 20, and 66 for sand, silt, and clay, respectively, and 14% organic matter. The soil was then dried, and 17.6 lb was added to 3-gal pots. Soil bulk density and volumetric field capacity were calculated using Soil Plant Air Water software (USDA ARS, Washington D.C.) with inputs of soil texture and organic matter to determine how much water was required to maintain 100% field capacity of the soil (volumetric field capacity ÷ bulk density × 100% × mass of soil = water needed). 'Diamond' rice was planted at 40 seeds/pot at 80% field capacity.

The experiment was designed as a three-factor-factorial completely randomized design with 4 replications. The factors being with or without a fenclorim seed treatment of 2.5 lb ai/1000 lb of seed, with or without Warrant at 2.5 pt/ac, and a planting depth of 0.25 or 1 in. Warrant was applied 5 days after planting (DPRE) using a spray chamber at 20 gal/ac with flat-fan 1100067 nozzles,

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and after application, pots were watered to 100% field capacity and maintained every 3 days.

Evaluations included weekly visual injury estimates (0–100% with 0% being no injury and 100% being rice death), as well as an average of 5 rice heights of each pot, and shoot counts of the entire pot. At 30 days after emergence (DAE), rice aboveground biomass was collected and weighed after drying. Pots were flooded approximately 21 DAE (4-leaf to tillering growth stage), and 260 lb/ac of urea (46-0-0) was applied at flooding to simulate field conditions. The experiment was analyzed within JMP Pro 16.1 (SAS Institute, Inc., Cary, N.C.), and all data were subjected to analysis of variance (ANOVA). Repeated measures analysis was used for injury, heights, and shoots to determine the effects of factors over time. All data were pooled over the two different experimental runs, and means were separated using Tukey's honestly significant difference ($\alpha = 0.05$).

Results and Discussion

Similar to previous research, the fenclorim seed treatment reduced rice injury caused by Warrant averaged over planting depth for all evaluation timings (Table 1) (Avent et al., 2020, 2021). Safening with chloroacetamide herbicides has been observed in other research where fenclorim reduced pretilachlor (another chloroacetamide herbicide less efficacious than acetochlor) injury (Chen et al., 2013; Quadranti and Ebner, 1983). Additionally, for each evaluation timing excluding 14 DAE, the deeper planting depth improved rice tolerance to acetochlor without the fenclorim seed treatment but did not provide commercial tolerance (Table 2). It is important to note despite planting depth and evaluation timing, injury caused by Warrant ranged from 15% to 60% without the fenclorim seed treatment, and with the fenclorim seed treatment, injury ranged from 0% to 20% (data not shown).

With applications of Warrant averaged over planting depth, the fenclorim seed treatment improved shoot counts relative to the no-fenclorim seed treatment (Table 3). Additionally, the rice stand was comparable with fenclorim and Warrant to the nontreated control at all evaluation timings. The fenclorim seed treatment also provided a safening effect in the presence of Warrant, where biomass was improved from 0.58 oz without fenclorim to 0.83 oz with fenclorim. Furthermore, without Warrant, the fenclorim seed treatment improved aboveground biomass from a nontreated average of 0.81 oz to 0.92 oz. Improved groundcover and above/belowground biomass have been observed in similar studies (Norsworthy et al., unpublished data).

It is important to note that initially, averaged over planting depth, the fenclorim seed treatment alone did reduce rice heights 7 and 14 DAE, but the plants had recovered by 21 DAE. (Table 1). The reduction in the height has been observed across several studies due to a delay in emergence by 1 to 2 days with the fenclorim seed treatment; however, the fenclorim seed treatment has never reduced stand or yield of rice, and rice has generally "recovered" by 21 DAE and surpassed the nontreated control by 28 DAE (Norsworthy et al., unpublished data). The delay in emergence is likely due to the metabolic stress induced by fenclorim, which likely causes enhanced rice growth by 28 DAE (Scarponi et al., 2005). In greenhouse experiments strictly comparing rice growth with and without a fenclorim seed treatment, belowground biomass was improved by 63%, which likely contributed to the improved aboveground biomass accumulation.

Practical Applications

Warrant is currently not labeled for U.S. rice production but would provide an alternative site of action for rice producers across Arkansas to control problematic weeds. Warrant and a fenclorim seed treatment can provide a nontraited herbicide option to suppress weedy rice (*Oryza sativa*, L.) with no potential of backcrossing or compromising the efficacy of weedy rice control. Based on this research, Warrant could be applied up to 2.5 pt/ac in rice treated with a fenclorim seed treatment of 2.5 lb ai/1000 lb of seed in early spring and provide commercial tolerance; however, more research needs to be conducted across multiple years and different soil types to confirm or refute these results.

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Literature Cited

Avent T.H., J.K. Norsworthy, C.B. Brabham, L. Bonilha-Piveta, M.C. Castner. 2020. Evaluation of a seed treatment for safening rice to rates of soil-applied acetochlor. *In*: K.A.K. Moldenhauer, B. Scott, and J. Hardke (eds.) B.R. Wells Arkansas Rice Research Studies 2019. Arkansas Agricultural Experiment Station Research Series 667:120-122.

Avent T.H., J.K. Norsworthy, L. Piveta, M.C. Castner, and J.W. Beesinger. 2021. Chloroacetamide herbicide use for weed control in rice. *In:* J. Hardke, X. Sha, and N. Bateman (eds.)B.R. Wells Arkansas Rice Research Studies 2020. Arkansas Agricultural Experiment Station Research Series 676:128–131.

Chen Y., X. Shen, and Y. Fang. 2013. Fenclorim effects on rice germination and yield. Can J Plant Sci 243:237–241.

Fogleman M., J.K. Norsworthy, T. Barber, and E. Gbur. 2019. Influence of formulation and rate on rice tolerance to early-season applications of acetochlor. Weed Technol. 33:239–245.

Godwin J., J.K. Norsworthy, and R.C. Scott. 2018. Application timing and rate effects on rice tolerance to very-long-chain fatty acid–inhibiting herbicides. Agron J. 110:1820–1828

Norsworthy J.K., M. Fogleman, T. Barber, and E. Gbur. 2019. Evaluation of acetochlor-containing herbicide programs in imidazolinone- and quizalofop-resistant rice. Crop Prot 122:98–105

Quadranti M. and L. Ebner. 1983. Sofit, a new herbicide for use in direct-seeded rice (wet-sown rice). Pages 405–412 in 9th Asian-Pacific Weed Science Society Conference. Phillippines.

Scarponi L., D. Del Buono, and C. Vischetti. 2005. Effect of pretilachlor and fenclorim on carbohydrate and protein formation in relation to their persistence in rice. Pest Manag. Sci. 61:371–376.

Table 1. Effect of Warrant (pt/ac), fenclorim (lb/1000 lb seed), and evaluation timing on rice heights and injury.

	Heights				Injury			
Effect	**7 DAE[†]**	**14 DAE**	**21 DAE**	**28 DAE**	**7 DAE**	**14 DAE**	**21 DAE**	**28 DAE**
	----------(in.)----------				----------(%)----------			
Warrant × fenclorim								
0 × 0	2.6 J[‡]	5.6 G	9.2 D	12.4 A	0	0	0	0
0 × 2.5	2.0 K	4.9 H	9.2 D	12.7 A	4 EFG	5 EF	1 G	1 G
2.5 × 0	1.2 L	3.8 I	7.6 F	10.4 C	35 A	33 AB	30 BC	29 C
2.5 × 2.5	1.9 K	5.3 GH	8.5 E	11.5 B	7 E	11 D	11 D	8 DE
RM *P*-value[§]	----------0.0094----------				----------<0.0001----------			

[†] DAE = days after emergence.
[‡] Different letters within the evaluations indicate a significant difference between treatments; means separated using Tukey's honestly significant difference at α = 0.05.
[§] *P*-values determined using analysis of variance with repeated measures.

Table 2. Effect of planting depth (in.), Warrant (pt/ac), and fenclorim (lb/1000 lb seed) on rice injury.

		Injury			
Effect		**7 DAE[†]**	**14 DAE**	**21 DAE**	**28 DAE**
		----------(%)----------			
Planting depth	Warrant × fenclorim				
0.25 in.	0 × 0	0	0	0	0
	0 × 2.5	5 C[§]	5	2 D	2 CD
	2.5 × 0	41 A	37	34 A	35 A
	2.5 × 2.5	7 C	10	10 C	6 CD
1 in.	0 × 0	0	0	0	0
	0 × 2.5	3 C	5	0 D	0 D
	2.5 × 0	29 B	29	26 B	23 B
	2.5 × 2.5	8 C	12	12 C	11 C
	P-value[§]	0.0052	0.1331	0.0187	0.0027
	RM *P*-value[¶]	----------0.2209----------			

[†] DAE = days after emergence.
[‡] Different letters within each column indicate a significant difference between treatments; means separated using Tukey's honestly significant difference at α = 0.05.
[§] *P*-values determined using analysis of variance.
[¶] *P*-values determined using analysis of variance with repeated measures.

Table 3. Effect of Warrant (pt/ac) and fenclorim (lb/1000 lb seed) on rice shoots and aboveground biomass.

	Shoots				
Effect	**7 DAE**[†]	**14 DAE**	**21 DAE**	**28 DAE**	**Biomass**
	------------------------------(count)------------------------------				**(oz)**
Warrant × fenclorim					
0 × 0	31 A[‡]	33 A	37 A	43 A	0.81 B
0 × 2.5	31 A	33 A	39 A	46 A	0.92 A
2.5 × 0	21 B	25 B	27 B	32 B	0.58 C
2.5 × 2.5	30 A	32 A	39 A	44 A	0.83 AB
P-value[§]	0.0002	0.0002	<0.0001	<0.0001	0.0374
RM *P*-value[¶]	-----------------------------0.7532--------------------------------				NA

[†] DAE = days after emergence.

[‡] Different letters within each column indicate a significant difference between treatments; means separated using Tukey's honestly significant difference at $\alpha = 0.05$.

[§] *P*-values determined using analysis of variance.

[¶] *P*-values determined using analysis of variance with repeated measures

Pennsylvania Smartweed Confirmed ALS-Inhibitor-Resistant in Arkansas

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Abstract

Pennsylvania smartweed [*Persicaria pensylvanica* (L.) M. Gomez] has become increasingly more difficult to control in Arkansas rice production systems. With the repeated use of acetolactate synthase (ALS)-inhibiting herbicides as the standard for control, more stress has been put on this site-of-action resulting in the potential consequence of resistance evolution. A greenhouse dose-response experiment was conducted in the spring and summer of 2021 at the University of Arkansas System Division of Agriculture's Lonoke Extension Center located near Lonoke, Arkansas, to assess if ALS-inhibitor-resistant Pennsylvania smartweed was present within the state. Multiple rates (0.25x, 0.5x, 1x, 2x, 4x, and 8x of a label rate) of two ALS-inhibiting herbicides [bispyribac-sodium (Regiment) and halosulfuron + prosulfuron (Gambit)] were applied to smartweed populations screened. Results indicated the Jackson County, Arkansas, Pennsylvania smartweed population to be between 5- and 10-fold resistant compared to the susceptible Lonoke County, Arkansas population based on the ED_{50} (estimated dose to reduce biomass by 50%). To achieve 90% control of the Jackson County, Pennsylvania smartweed population, it required a 17x rate of Gambit and 48x rate of Regiment allowed by the label. These rates for control are not economically feasible nor legal due to the herbicide label. An alternate mode-of-action, development of a new chemistry, and/or implementation of diverse management strategies are needed to help combat this newly documented resistant weed.

Introduction

Smartweed species (*Persicaria* spp.) have been reported as important weeds to manage in Mid-south rice acres (Norsworthy et al., 2013). Acetolactate synthase (ALS)-inhibiting herbicides have become the go-to options for successfully managing these species' postemergence in rice (Barber et al., 2021). The heavy reliance on ALS-inhibitor chemistries for smartweed control in rice resulted in a population of Pennsylvania smartweed [*Persicaria pensylvanica* (L.) M. Gomez] from southeast Missouri being previously confirmed ALS-inhibitor-resistant (Varanasi et al., 2018). No such resistance has been confirmed in Arkansas; however, recent suspicions and reports of suspected ALS-inhibitor-resistant smartweed have begun to emerge. As a result, the objective of this research was to assess whether an Arkansas Pennsylvania smartweed population had evolved ALS-inhibitor resistance.

Procedures

A greenhouse dose-response experiment was conducted in the spring and summer of 2021 at the University of Arkansas System Division of Agriculture's Lonoke Extension Center located near Lonoke, Arkansas. Two Pennsylvania smartweed populations (one suspected resistant population from Jackson County, Arkansas, and one susceptible population from Lonoke County, Arkansas) were subjected to multiple rates (0.25x, 0.5x, 1x, 2x, 4x, and 8x of a label rate) of two ALS-inhibiting herbicides [bispyribac-sodium (Regiment) and halosulfuron + prosulfuron (Gambit)]. The 1x label rates used for Regiment and Gambit were 0.5 and 2 oz/ac, respectively, and appropriate adjuvants were included in each treatment as indicated by the herbicide labels. Treatments were sprayed using a single-nozzle research track sprayer (DeVries Manufacturing) calibrated to deliver 10 gal/ac using an XR110015 EVS nozzle. A minimum of 3 replications (plants) were evaluated per run, and 2 separate experimental runs were conducted. At 28 days after treatment, plants were harvested and weighed for aboveground biomass measurements. Biomass data were standardized compared to the nontreated control and analyzed using the dose-response package (drc) in R v. 4.0.3 (Ritz et al., 2015). Three parameter log-logistic regression curves were fit to the data with maximum values fixed at 100.

Results and Discussion

Results of the greenhouse dose-response study indicate the Jackson County, Arkansas, Pennsylvania smartweed population to be between 5- and 10-fold resistant based on the estimated dose to reduce biomass by 50% (ED_{50}) and between 38- and 60-fold resistant to reduce biomass by 90% (ED_{90}) for both Gambit and Regiment, respectively, compared to the susceptible standard (Table 1). Dose-response curve figures for both Gambit (Fig. 1) and Regiment (Fig. 2) illustrate the reduced control observed with each ALS-inhibiting herbicide on the Jackson County population compared to the Lonoke County susceptible. This is also demonstrated in the images taken from the greenhouse experiment for the resistant (Fig. 3) and susceptible (Fig. 4) populations at 28 days following the application. To successfully control the Jackson

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County Pennsylvania smartweed population (reduce biomass by 90%), it would require a 34.6 and 24.4 oz/ac rate of Gambit and Regiment, respectively. This equates to approximately 17 and 48 times more than the labeled rates of Gambit and Regiment, respectively. These rates for control are not economically feasible nor legal due to the herbicide label.

Practical Applications

This research confirms the existence of ALS-inhibitor-resistant Pennsylvania smartweed within Arkansas. Additionally, as the Jackson County population was confirmed resistant to both Regiment and Gambit, this demonstrates the resistance is present across different chemical families within the ALS-inhibitor site-of-action. This can be extremely problematic for rice producers within the state as it effectively removes an entire site-of-action available for the control of Pennsylvania smartweed. The remaining options would include Basagran at 2 pt/ac, propanil at 4 qt/ac, and Aim at 1.25 fl oz/ac. However, as all of these are contact herbicides, adequate coverage and applying when smartweed is small (~4 inches in height) are a must for successful control. Sequential applications of these herbicides will also often be required for complete control. An alternate mode-of-action, development of a new chemistry, and/or implementation of diverse management strategies are needed to help combat this newly documented resistant weed.

Acknowledgments

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Literature Cited

Barber, L.T., T.R. Butts, J.W. Boyd, K. Cunningham, G. Selden, J.K. Norsworthy, N.R. Burgos, and M. Bertucci. 2021. Recommended chemicals for weed and brush control. University of Arkansas System Division of Agriculture, Cooperative Extension Service MP44, Little Rock, Ark.

Norsworthy, J.K., J. Bond, and R.C. Scott. 2013. Weed management practices and needs in Arkansas and Mississippi rice. Weed Technol. 27:623–630. Available at https://dx.doi.org/10.1614/WT-D-12-00172.1

Ritz, C., F. Baty, J.C. Streibig, and D. Gerhard. 2015. Dose-response analysis using R. PLoS One 10, e0146021. Available at https://dx.doi.org/10.1371/journal.pone.0146021

Varanasi, V.K., J.K. Norsworthy, C. Brabham, and R.C. Scott. 2018. Characterization of acetolactate synthase (ALS)-inhibitor resistance in Pennsylvania smartweed (*Persicaria pensylvanica*). Weed Sci. 66:710–714. Available at https://dx.doi.org/10.1017/wsc.2018.44

Table 1. Estimated herbicide doses required to achieve 50% (ED_{50}) and 90% (ED_{90}) Pennsylvania smartweed biomass reduction.

	Susceptible		Resistant		
Herbicide	**ED_{50}[a]**	**ED_{90}[b]**	**ED_{50}**	**ED_{90}**	**1x label rate**
	----------oz/ac----------		----------oz/ac----------		oz/ac
Gambit	0.02	0.9	0.2	34.6	2.0
Regiment	0.006	0.4	0.03	24.4	0.5

[a] Dose needed to reduce biomass by 50%.

[b] Dose needed to reduce biomass by 90%.

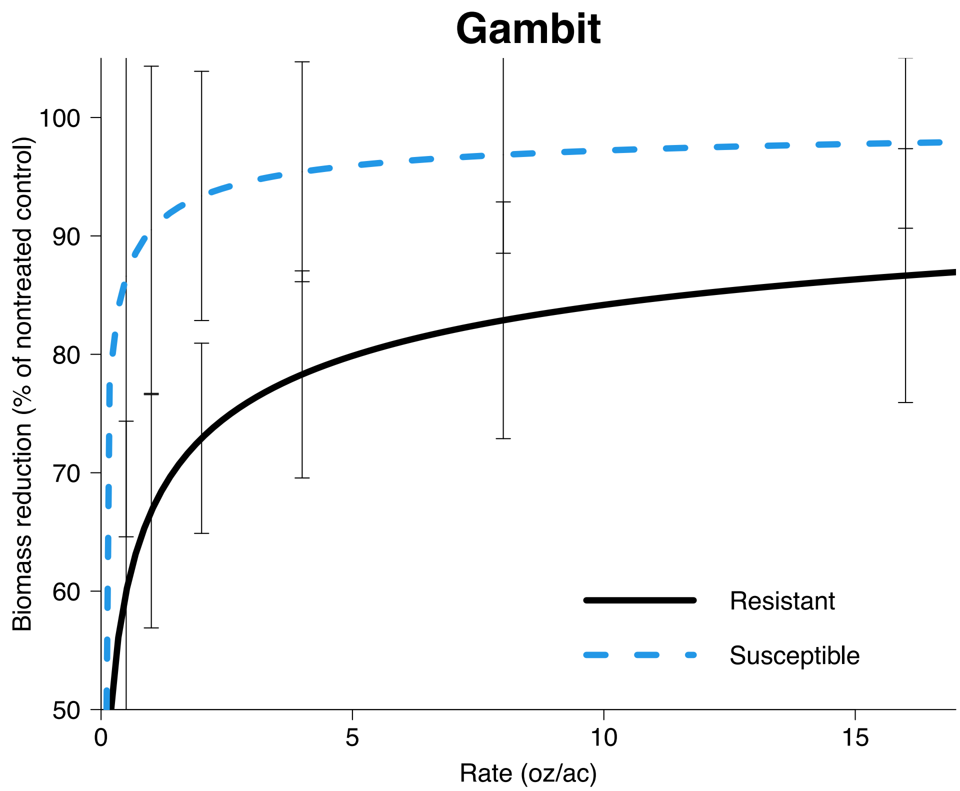

Fig. 1. Dose-response curves for a suspected resistant and susceptible Pennsylvania smartweed population following an application of Gambit (halosulfuron + prosulfuron) herbicide. The 1x label rate of Gambit was 2 oz/ac.

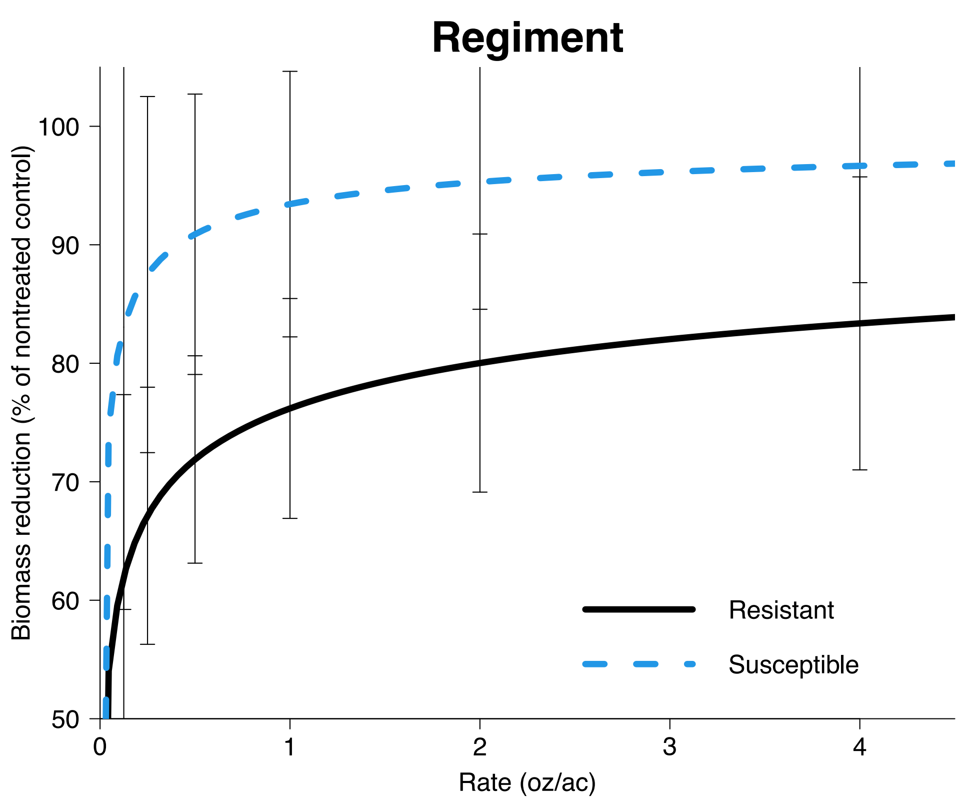

Fig. 2. Dose-response curves for a suspected resistant and susceptible Pennsylvania smartweed population following an application of Regiment (bispyribac-sodium) herbicide. The 1x label rate of Regiment was 0.5 oz/ac.

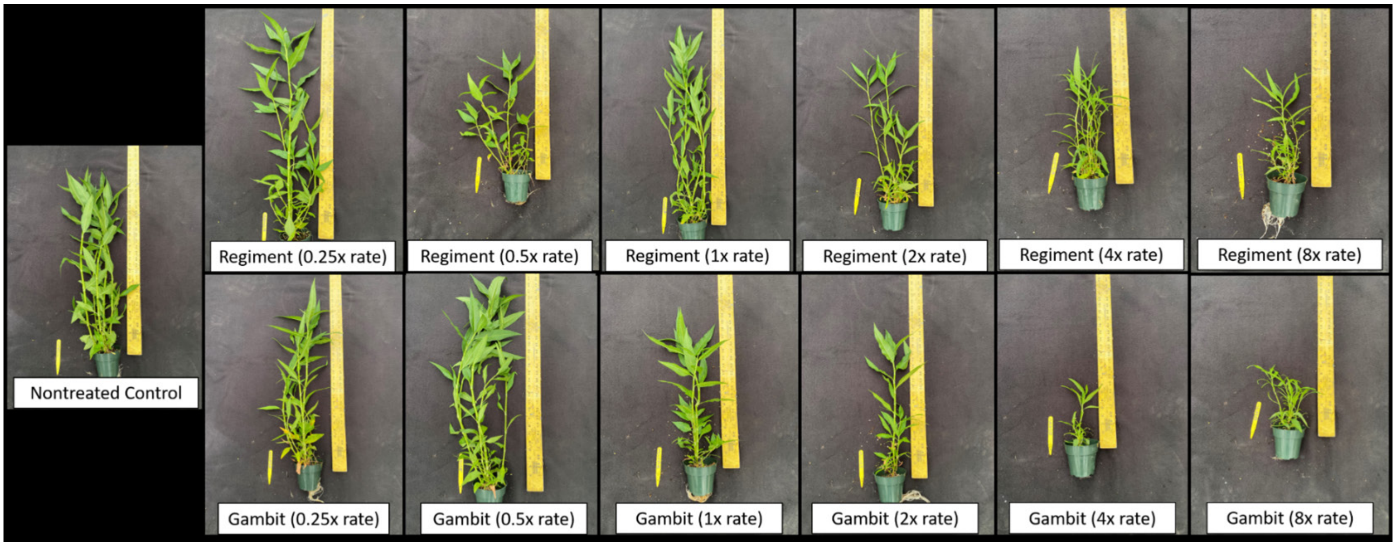

Fig. 3. Dose-response of suspected acetolactate synthase (ALS) inhibitor resistant smartweed from Jackson County, Arkansas, 28 days after treatment of bispyribac-sodium (Regiment) and halosulfuron + prosulfuron (Gambit). The 1x rate for Regiment and Gambit was 0.5 and 2 oz/ac, respectively.

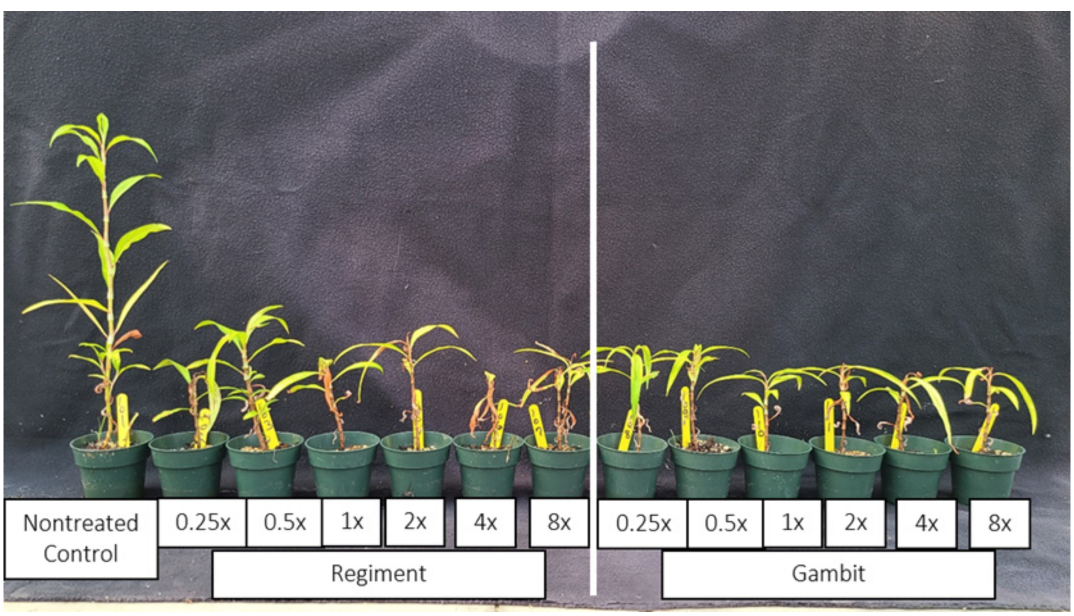

Fig. 4. Dose-response of susceptible smartweed from Lonoke County, Arkansas, 28 days after treatment of bispyribac-sodium (Regiment) and halosulfuron + prosulfuron (Gambit). The 1x rate for Regiment and Gambit was 0.5 and 2 oz/ac, respectively.

Evaluation of Rice Tolerance to Fluridone

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

Abstract

Fluridone is a pigment-inhibiting herbicide with applications in cotton [*Gossypium hirsutum* (L.)] (Brake®) and aquatic systems (SonarOne®). The success of Brake in Arkansas cotton systems has led the University of Arkansas System Division of Agriculture to evaluate this herbicide as an alternative for residual broadleaf control in flooded and furrow-irrigated rice systems. An experiment was conducted near Stuttgart, Arkansas, in 2021 to evaluate the tolerance of a drill-seeded inbred rice cultivar to early-season applications of Brake. Treatments were arranged as a two-factor factorial randomized complete block design with four replications. The first factor was herbicide rate, and the second was application timing. Brake was applied at 16 and 32 fl oz/ac at the preemergence (PRE), delayed-preemergence (DPRE), 1–2 leaf, and postflood (POSTFLD) timings. An interaction was observed between herbicide rate and application timing at 28 days after treatment (DAT), as well as at 28 days after postflood (DA POSTFLD). Except for comparable injury at the POSTFLD timing, visual injury from Brake applied at 16 fl oz/ac was less than the 32 fl oz/ac rate for each assessment. The greatest amount of injury at 28 DAT and 28 DA POSTFLD resulted from a postemergence application at the 1–2 leaf rice growth stage at the 32 fl oz/ac rate (33% and 31%, respectively). Brake applied at 16 fl oz/ac at the PRE and DPRE timing caused less than 10% injury to rice for each assessment, which is an acceptable level of crop injury. Overall, rice was tolerant to Brake applied at 16 fl oz/ac, and crop injury did not appear to increase with the establishment of a continuous flood.

Introduction

Brake® (fluridone) is a Weed Science Society of America (WSSA) group 12 (Anonymous, 2019), pigment-inhibiting herbicide with applications spanning from cotton (*Gossypium hirsutum* L.) to aquatic weed control. In Arkansas, Brake is often utilized as an effective residual herbicide for small-seeded broadleaf weeds, specifically Palmer amaranth (*Amaranthus palmeri* S. Wats), and suppression of several weedy grass species. The success of Brake in Arkansas cotton systems has led to efforts by the University of Arkansas System Division of Agriculture to evaluate and potentially repurpose Brake as an additional mode of action (MOA) for use in flooded and furrow-irrigated rice systems. The integration of Brake as an early season residual option in rice would provide an opportunity to relieve pressure on an already limited selection of postemergence (POST) herbicides for flooded and furrow-irrigated rice. As weeds continue to evolve and remain a challenge for many producers across the Mid-south, any additional chemical control option or new MOA could aid in protecting yield potential in all production systems.

Procedures

A field experiment was conducted at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center near Stuttgart, Arkansas, in 2021 to evaluate rice tolerance to Brake. An inbred cultivar (Diamond) was drill-seeded into 6 by 17 ft plots and maintained as a conventional paddy rice. The experiment was arranged as a two-factor factorial (herbicide rate by application timing) randomized complete block design with four replications. Brake was applied at 16 and 32 fl oz/ac, which is equivalent to 0.15 and 0.30 lb ai/gal, respectively, at the preemergence (PRE), delayed-preemergence (DPRE), 1–2 leaf, and postflood (POSTFLD) (5 days after flood) application timings with a CO_2-pressurized backpack sprayer delivering a spray volume of 15 gal/ac. Following each application timing, visual ratings of crop injury were taken at 7, 14, 21, and 28 days after treatment (DAT) on a 0% to 100% scale, with 0% representing no injury and 100% indicative of crop death. Grain yield was not collected due to early termination of the experiment. All injury data collected from this experiment were subjected to analysis of variance in JMP Pro 16, and means were separated using Fisher's protected least significant difference ($\alpha = 0.05$).

Results and Discussion

At 28 DAT, injury to rice was observed to be a function of rate and application timing (Fig. 1). When Brake was applied at the 16 fl oz/ac rate, injury was less at each respective application timing compared to the 32 fl oz/ac rate, with an exception at the POSTFLD timing. Less than 1% injury was observed to POSTFLD applications regardless of the rate of Brake applied, suggesting there are acceptable levels of crop safety when a flood is present, although the advantage of preflood weed control would be compromised. The greatest amount of injury was caused by a POST application at the 1–2 leaf rice growth stage at the 32 fl oz/ac rate (33%). Overall, the degree of injury caused by the 32 fl oz/ac rate would be unacceptable for rice producers; however,

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the 16 fl oz/ac rate shows promise as a PRE or DPRE option with ≤5% injury for either timing.

Twenty-eight days following flood initiation, the same rate by application timing interaction occurred, with injury closely resembling what was observed at 28 DAT (Fig. 2). The establishment of a continuous flood did not appear to increase injury to rice for any preflood application, indicating that the 16 fl oz/ac rate may be a viable PRE or DPRE option in a conventional flooded system. Additionally, the lack of rice injury observed from a POSTFLD application at 28 DAT (≤1%) and 28 DA POSTFLD (≤1%) may provide alternatives to what is currently available for aquatic weed control (McCowen et al., 1979). Based on these findings, additional experiments primarily focusing on crop safety will be conducted in continuous and furrow-irrigated systems, as well as the potential integration of Brake into herbicide programs.

Practical Applications

The results of this experiment provide insight into the potential use of Brake as a residual or aquatic herbicide option in conventional rice systems. The overall minimal injury observed from Brake at 16 fl oz/ac for PRE and DPRE application timings prior to flood establishment, as well as both rates postflood, is promising for the continuation of rice research with this herbicide. With Palmer amaranth being the most problematic broadleaf weed in furrow-irrigated rice production, the effectiveness and length of residual activity that Brake provides in current row-crop applications could help to combat Palmer amaranth and other broadleaf species on furrow-irrigated rice acres. Although more research is needed to fully understand the extent of crop safety, the possibility of a new MOA in Arkansas rice production could relieve selection pressure placed on POST-applied herbicides.

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.

Literature Cited

Anonymous (2019) Brake product label. SePRO Corporation. Accessed: 19 January 2022. Available at http://www.cdms.net/ldat/ldU7I000.pdf

McCowen M.C., C.L. Young, and S.D. West. 1979. Fluridone, a new herbicide for aquatic plant management. J Aquat. Plant Manag. 17:27-30.

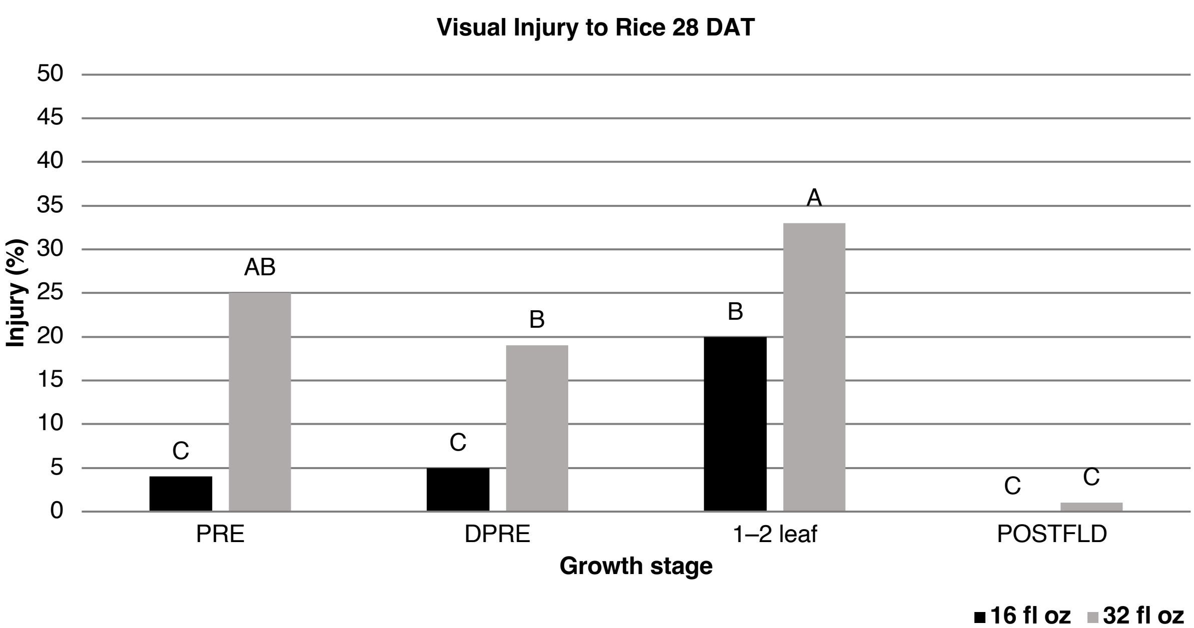

Fig. 1. Visual injury to rice 28 days after an application of fluoridone (Brake) at 16 and 32 fl oz/ac near Stuttgart, Arkansas. Means followed by the same letter are not different (α = 0.05). DAT stands for days after treatment; DPRE, delayed-preemergence; POSTFLD, postflood; PRE, preemergence.

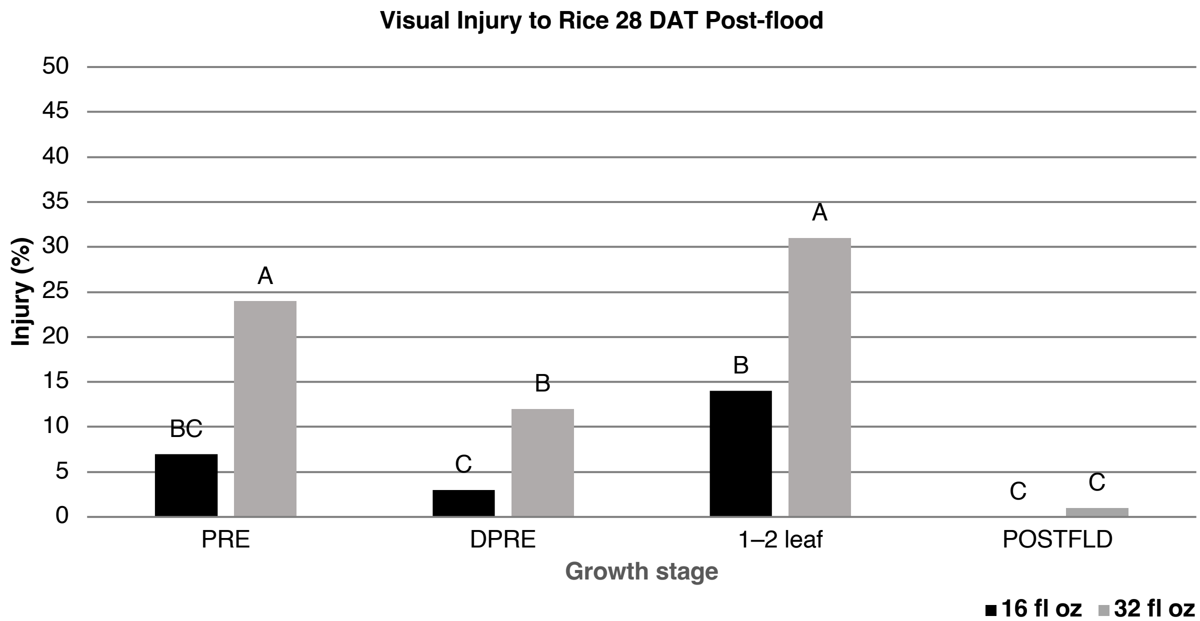

Fig. 2. Visual injury to rice 28 days after flood initiation from an application of fluoridone (Brake) at 16 and 32 fl oz/ac near Stuttgart, Arkansas. Means followed by the same letter are not different (α = 0.05). DA stands for days after treatment; DPRE, delayed-preemergence; POSTFLD, postflood; PRE, preemergence.

Does Coating Loyant on Urea Reduce Risk of Off-target Movement to Soybean?

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

Abstract

Following the commercial launch of Loyant® (florpyrauxifen-benzyl) in 2018, frequent off-target movement of the herbicide to adjacent soybean [*Glycine max* (L.) Merr] fields was observed. Hence, a field experiment was conducted in 2020 and 2021 in Fayetteville, Arkansas, to evaluate soybean injury following low rates (0 oz ai/ac to 0.094 oz ai/ac) of florpyrauxifen-benzyl applied either as a foliar spray or coated on urea at the V3 stage. During both years, the response of soybean was evaluated when florpyrauxifen-benzyl was applied in a wide-row (36 in.) system at 7, 14, 21, and 28 days after application. In both years, 100% soybean injury (death) occurred following foliar spray applications. However, when coated on urea, the maximum soybean injury from florpyrauxifen-benzyl at 0.094 oz ai/ac resulted in only 20% and 23% soybean injury in 2020 and 2021, respectively. At all timings, equivalent rates of florpyrauxifen-benzyl coated on urea caused less injury than that of the foliar spray applications. No deleterious effect on yield was observed in 2020 and 2021 from any florpyrauxifen-benzyl coated on urea treatment when compared to the nontreated plots, but all foliar spray treatments caused a negative effect on yield. Overall, florpyrauxifen-benzyl coated on urea reduced soybean injury by 50 to 91 and 55 to 96 percentage points in 2020 and 2021, respectively, across all rating dates when compared to foliar spray applications. Coating florpyrauxifen-benzyl onto urea appears to substantially reduce the risk for off-target movement of the herbicide onto soybean, and future research needs to establish the effectiveness of this application technique on weed control.

Introduction

Florpyrauxifen-benzyl is a Weed Science Society of America (WSSA) group 4 synthetic auxin herbicide commercialized in rice (*Oryza sativa* L.) in 2018 as Loyant®. As a rice herbicide, florpyrauxifen-benzyl offers greater than 75% control of broadleaf signalgrass [*Urochloa platyphylla* (Munro ex C. Wright) R.D. Webster], barnyardgrass [*Echinochloa crus-galli* (L.) P. Beauv.], Amazon sprangletop [*Diplachne panicoides* (J. Presl) McNeil], large crabgrass [*Digitaria sanguinalis* (L.) Scop.], northern jointvetch [*Aeschynomene virginica* (L.) Britton, Sterns & Poggenb.], hemp sesbania [*Sesbania herbacea* (Mill.) McVaughn], pitted morningglory (*lpomoea lacunosa* L.), Palmer amaranth (*Amaranthus palmeri* S. Watson), yellow nutsedge (*Cyperus esculentus* L.), rice flatsedge (*Cyperus iria* L.), and smallflower umbrellasedge (*Cyperus difformis* L.) when sprayed at 0.5 oz ai/ac (Miller and Norsworthy, 2018a).

As of 2020, soybean and rice are the top 2 agronomic grains planted and harvested in Arkansas (USDA-NASS, 2020). Although florpyrauxifen-benzyl is an effective rice herbicide, there is potential for off-target movement of the herbicide to adjacent soybean fields. When evaluating multiple crops {soybean, cotton (*Gossypium hirsutum* L.), corn (*Zea mays* L.), grain sorghum [*Sorghum bicolor* (L.) Moench ssp. bicolor], sunflower (*Helianthus annuus* L.)} to florpyrauxifen-benzyl, it was concluded that soybean exhibited the greatest sensitivity to the herbicide (Miller and Norsworthy, 2018b). In Arkansas, 51% of herbicide applications were reported by aerial application, and herbicide drift was identified as a main concern (Butts et al., 2021). To reduce the potential of off-target movement via herbicide drift, coating herbicides onto fertilizers may be one possible solution to the problem. In conservation tillage systems, herbicide-coated fertilizers can help create a uniform coverage because fertilizer granules can infiltrate a crop canopy and residue more effectively (Kells and Meggett,1985). However, under-application can lead to decreased weed control, and over-application can lead to increased crop injury (Wells and Green, 1991). Due to various risks associated with applications of florpyrauxifen-benzyl, experiments were conducted to determine if coating florpyrauxifen-benzyl onto urea would reduce soybean injury from off-target movement and allow for florpyrauxifen-benzyl to be applied without concern of soybean injury linked to an application.

Procedures

A field experiment evaluating the risk of off-target movement to soybean of florpyrauxifen-benzyl coated on urea was conducted in 2020 and 2021 at the Milo J. Shult Agricultural Research and Extension Center in Fayetteville, Arkansas. In both years, the experiment was conducted as a two-factor randomized complete block design where seven florpyrauxifen-benzyl rates (0 to 0.094 oz ai/ac) and two application methods (foliar spray and coated) were the factors with 4 replications. Credenz soybean variety 4410GTLL (2020) and 4539GTLL (2021) were planted on 36-in. wide raised beds at a seeding rate of 145,000 seeds/ac. Soybean varieties were different between years due to the discontinuation of 4410GTLL. The center (6 ft) of each plot was treated to prevent contamination from adjacent plots. Foliar spray

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florpyrauxifen-benzyl rates of 0, 0.003, 0.006, 0.012, 0.024, 0.047, and 0.094 oz ai/ac were applied to simulate sublethal doses that may occur from spray drift. Herbicide-coated urea was weighed at each rate to treat 120 ft^2 of each plot for coated applications. Florpyrauxifen-benzyl at 0.5 oz ai/ac was coated onto 283 lb/ac of urea, and rates equivalent to foliar spray applications were measured and applied to compare injury directly between foliar spray and coated applications. Estimated visual injury ratings were recorded at 7, 14, 21, and 28 days after the application and evaluated using a 0–100 scale, where 0 represents no injury and 100 crop death. Grain yield was harvested from the two center rows or center of each plot using a small-plot combine. Grain moisture was adjusted to 13%. All injury data were subjected to regressional analysis using a Weibull Growth Model for injury level prediction. All yield data were subjected to regressional analysis using an Exponential 2P Model to predict yield.

Results and Discussion

In both years, coating florpyrauxifen-benzyl onto urea decreased levels of soybean injury (Figs. 1 and 2). At 21 days after treatment with florpyrauxifen-benzyl at 0.094 oz ai/ac, maximum visual soybean injury caused by the herbicide coated on urea was 20% and 23% in 2020 and 2021, respectively. Conversely, the same rate of florpyrauxifen-benzyl caused complete loss of the crop in both years when applied as a foliar spray. Likewise, as rates of foliar spray florpyrauxifen-benzyl applications increased, soybean injury increased (Miller and Norsworthy, 2018b). Across all rating timings, coating florpyrauxifen-benzyl onto urea decreased soybean injury by 50 to 91 and 55 to 96 percentage points in 2020 and 2021, respectively. Coating florpyrauxifen-benzyl onto urea caused no deleterious effect on yield in both years; whereas, low rates applied as a foliar spray caused a reduction in yield (Figs. 3 and 4). The experiment, both years, resulted in complete soybean yield loss when florpyrauxifen-benzyl at 0.094 oz ai/ac was foliar applied. Coating florpyrauxifen-benzyl onto urea appears to be an effective application method to reduce injury from off-target movement of the herbicide.

Practical Applications

Florpyrauxifen-benzyl is currently being applied aerially in limited amounts in Arkansas. Coating florpyrauxifen-benzyl onto urea would provide a safer, low-drift means of herbicide application, as well as potentially decreasing the required number of aerial applications at the preflood timing in rice by combining a herbicide and fertilizer application. Urea granules are larger in diameter and density than spray droplets and would be less likely to move off-target from a physical drift occurrence due to increased downward terminal velocity (Hofstee, 1992). Florpyrauxifen-benzyl is needed as an additional herbicide option with the increasing amounts of herbicide resistance in rice weeds.

Acknowledgments

This research was conducted in cooperation with Corteva Agriscience Inc. We would like to thank Corteva for partially funding this research and providing the florpyrauxifen-benzyl. Support for this research was also provided by the Arkansas Rice Checkoff Program administered by the Arkansas Rice Research and Promotion Board. Lastly, the facilities were made possible by the University of Arkansas System Division of Agriculture.

Literature Cited

Butts, T.R., L.T. Barber, J.K. Norsworthy, and J. Davis. 2021. Survey of ground and aerial herbicide application practices in Arkansas agronomic crops. Weed Technol. 35:1-11.

Hofstee, J.W. 1992. Handling and spreading of fertilizers: part 2, physical properties of fertilizers, measuring methods and data. J. Agric. Eng. Res. 53:141-162.

Kells, J.J. and W.F. Meggit. 1985. Conservation tillage and weed control. Pages 123-129 in A Systems Approach to Conservation Tillage (1st edition). CRC Press, Boca Raton, Fla.

Miller, M.R. and J.K. Norsworthy. 2018a. Florpyrauxifen-benzyl weed control spectrum and tank mix compatibility with other commonly applied herbicides in rice. Weed Technol. 32:319-325.

Miller, M.R. and J.K. Norsworthy. 2018b. Row crop sensitivity to low rates of foliar-applied florpyrauxifen-benzyl. Weed Technol. 32:398-403.

USDA-NASS. 2020. United States Department of Agriculture National Agricultural Statistics Service. 2020 State Agriculture Overview. Arkansas. Accessed 28 January 2022. Available at https://www.nass.usda.gov/Quick_Stats/Ag_Overview/stateOverview.php?state=ARKANSAS

Wells, K.L. and J.D. Green. 1991. Using solid, bulk blended mix-grade fertilizers. Soil Science News and Views 12: 1-3. University of Kentucky Plant and Soil Sciences.

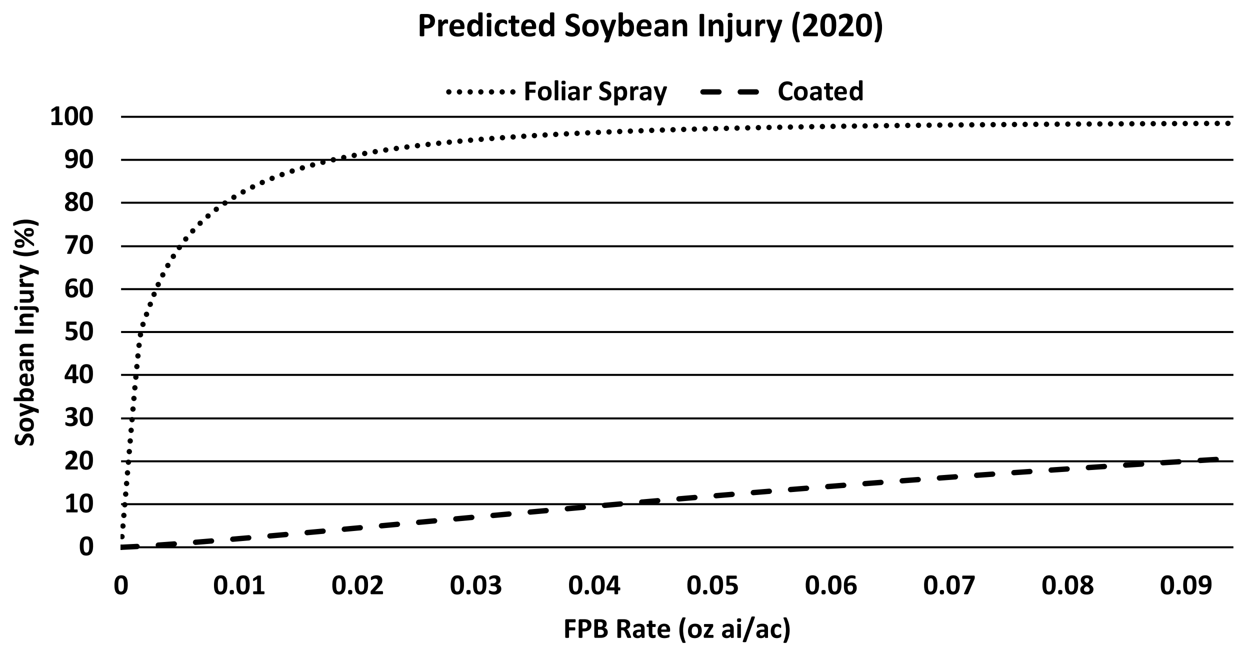

Fig. 1. Weibull growth model, Y = a(1-EXP(-(rate/b)c)), of predicted soybean visual injury 21 days after treatment of florpyrauxifen-benzyl (FPB) applications in 2020. Foliar treatments produced an R^2 = 0.985 and coated treatments produced an R^2 = 0.872.

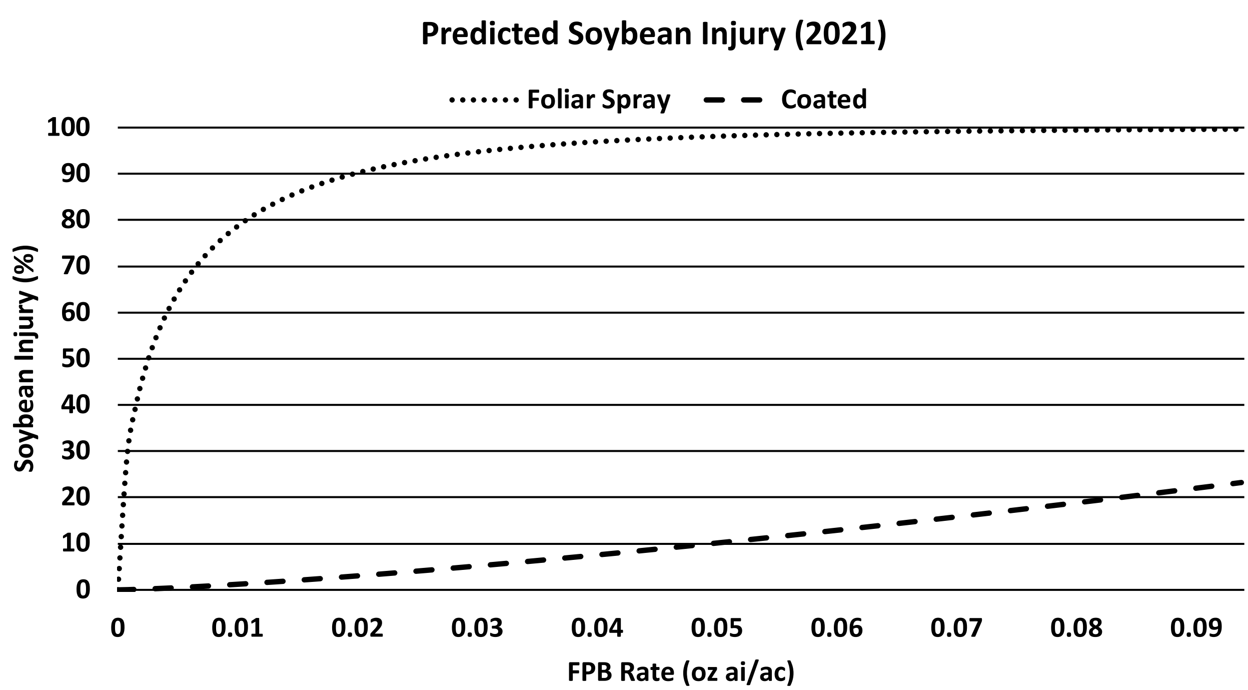

Fig. 2. Weibull growth model, Y = a(1-EXP(-(rate/b)c)), of predicted soybean visual injury 21 days after treatment of florpyrauxifen-benzyl (FPB) applications in 2021. Foliar treatments produced an R^2 = 0.896 and coated treatments produced an R^2 = 0.819.

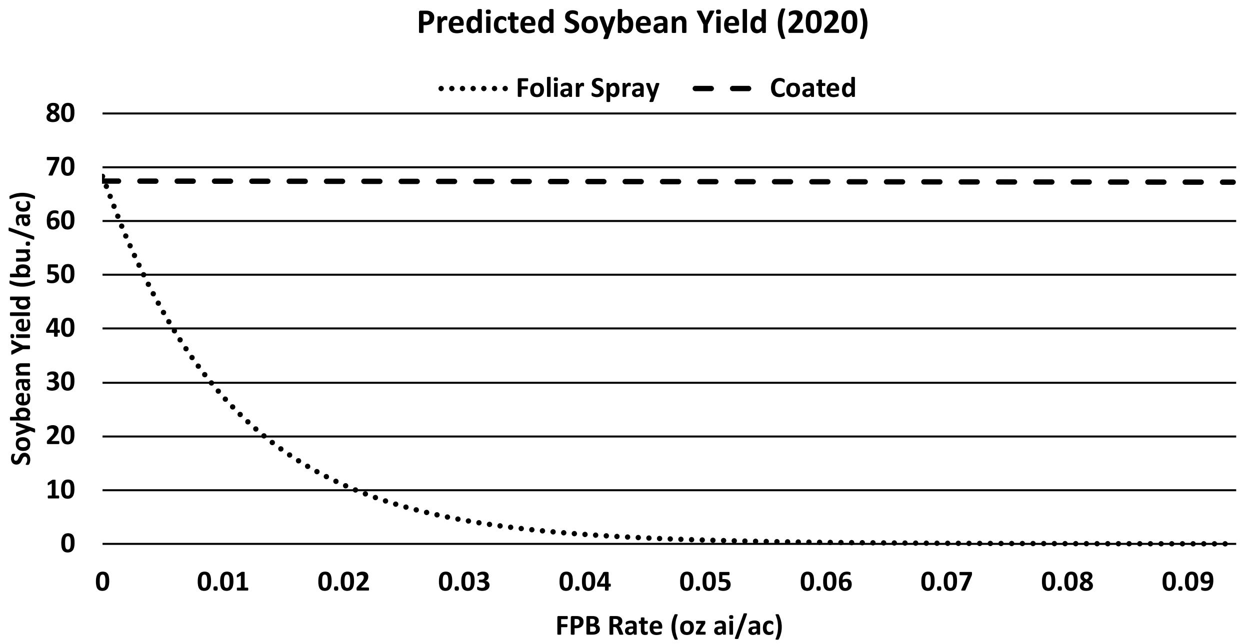

Fig. 3. Exponential 2P model, Y = a(EXP(b*rate)), of predicted soybean yield in 2020. Florpyrauxifen-benzyl (FPB) foliar treatments produced an R^2 = 0.939 and coated treatment means were averaged due to no significant differences.

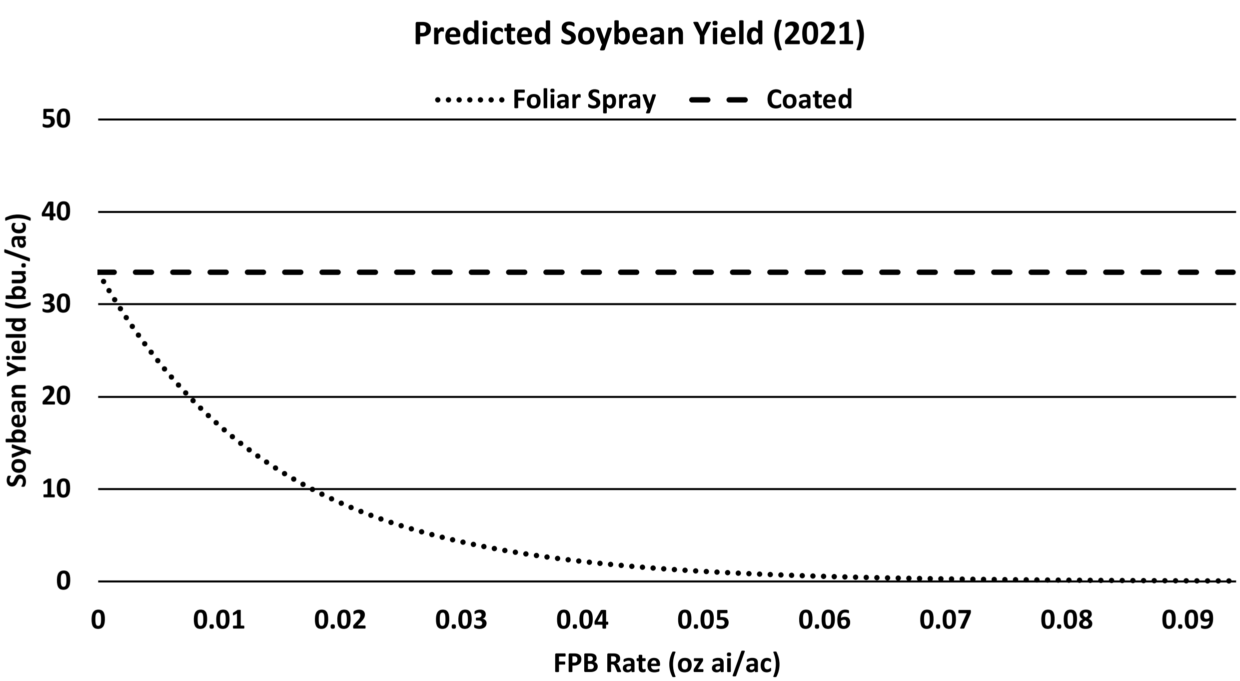

Fig. 4. Exponential 2P model, Y = a(EXP(b*rate)), of predicted soybean yield in 2021. Florpyrauxifen-benzyl (FPB) Foliar treatments produced an R^2 = 0.876, and coated treatment means were averaged due to no significant differences.

Salvage Herbicide Options for Controlling Barnyardgrass Preflood and Postflood in Arkansas Rice

B.M. Davis,[1] T.R. Butts,[1] J.K. Norsworthy,[2] L.T. Barber,[1] L.M. Collie,[1] and C. Sandoski[3]

Abstract

The control of barnyardgrass in Arkansas rice (*Oryza sativa*, L.) systems has plagued growers since the crop was first cultivated in the state. Now resistance to herbicides used in Arkansas production programs has complicated barnyardgrass control, and potential delays in herbicide applications due to weather events have made that control even more difficult. Two studies were conducted at the University of Arkansas at Pine Bluff Small Farm Outreach Center near Lonoke to evaluate potential salvage options for the control of barnyardgrass [*Echinochloa crus-galli* (L.) P. Beauv.] in Arkansas rice production. Ten herbicide treatments were applied at preflood and postflood in two separate trials. Results show that Ricestar HT alone did not control barnyardgrass in a last resort salvage situation. Ricestar HT mixed with several other herbicide options at full rates (Facet L, Regiment, Postscript, and Clincher) provided adequate control of barnyardgrass in this salvage situation when applied both preflood and postflood. Rough rice yields followed barnyardgrass control trends and demonstrated that several salvage treatment options saved yield potential. One aspect that needs to be carefully examined is whether the salvage treatment was economically feasible and whether saving yield potential was profitable to the grower.

Introduction

Arkansas grew an estimated 1.2 million acres of rice (*Oryza sativa*, L.) in 2021 and is ranked number 1 among states producing rice. Barnyardgrass [*Echinochloa crus-galli* (L.) P. Beauv.] has become the most troublesome weed for rice producers in the last few years (Norsworthy et al., 2013). Resistance to many of the most commonly used rice herbicides has made barnyardgrass control even more difficult (Heap, 2022). Herbicide application timings and overlapping of effective residual herbicides are key for success and season-long weed control. However, growers are at the mercy of environmental conditions that can severely impact herbicide applications. Wind and weather events can cause delays in applications when application timings are key. This delay in application could stretch for lengthy periods of time. This, in turn, allows for problematic weeds such as barnyardgrass to grow to sizes that are extremely difficult to control and reach a salvage situation. Therefore, more emphasis is put on an effective salvage herbicide option to control barnyardgrass and allow the rice to canopy, thus reducing the ability for other weeds to grow. The objective of this research was to determine successful barnyardgrass salvage herbicide programs in conventionally (flooded) grown rice in Arkansas.

Procedures

Two studies were conducted in the summer of 2021 at the University of Arkansas at Pine Bluff Small Farm Outreach Center near Lonoke, Arkansas. Hybrid rice cultivar RT7521 FP was drill seeded at 30 lb/ac on 7.5-in. spacings. The experimental design was a randomized complete block with four replications. Ten herbicide treatments were applied at preflood and postflood with a tractor-mounted sprayer equipped with AI 110015 tips calibrated to deliver 10 gal/ac (Table 1). Rice was monitored and managed according to university recommendations regarding fertility and pest control. Visual estimations of weed control were taken weekly and were estimated using a scale of 0% to 100%, where 0% is no control and 100% is complete plant death. Yield was harvested with a plot combine and adjusted to 12.5% moisture. Data were subjected to analysis of variance, and means were separated using Fisher's protected least significant difference test at a 5% level of significance.

Results and Discussion

At 2 weeks after preflood (WA PREFLD) application, barnyardgrass control was ≤60% with all herbicide programs (Fig. 1). Ricestar HT tank-mixed with Postscript or Regiment were the only treatments that provided marginal control at 2 WA PREFLD (>50%). Several herbicides, including Ricestar HT tank-mixed with Postscript, Regiment, and Facet L + Regiment, achieved >60% control of barnyardgrass at 2 weeks after postflood (WA POSTFLD) application (Fig. 1). At 3 WA PREFLD, all treatments controlled barnyardgrass ≤75% (Fig. 2). At 3 WA POSTFLD, Ricestar HT + Postscript, Ricestar HT + Regiment, and Ricestar HT + Regiment + Facet each provided over 90% control of barnyardgrass (Fig. 2). Similar treatments between the preflood and postflood applications were considerably lower with the preflood application compared to the postflood application.

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[2] Distinguished Professor, University of Arkansas System Division of Agriculture, Department of Crop, Soil, and Environmental Sciences, Fayetteville.

[3] Gowan USA, Collierville, Tennessee.

This may be due to the lack of moisture during the preflood applications, and weeds may have been stressed. By preharvest, all postflood treatments had provided adequate control above 80% except for Ricestar HT alone at both rates (Fig. 3). Preflood applications of Ricestar HT alone and tank-mixed with Clincher at both rates were the only treatments that were below 80% control prior to harvest. Rough rice yield trends mimic the barnyardgrass control assessments, with treatments 5, 6, 9, 10, and 11 having the greatest numerical yields for both application timings (Fig. 4). Results suggest that mixtures with other barnyardgrass herbicides at full label rates should be used to control barnyardgrass in a salvage situation and help maximize yields. However, the use of graminicides (Clincher and Ricestar HT) either alone or tank-mixed did not provide adequate control and was also reflected in rough rice yields. Initial control data may suggest that waiting for a flush of water as with the postflood applications would be key for control; however, by harvest, both preflood and postflood applications control were similar.

Practical Applications

Initial findings in this study suggest that growers should use a tank-mix option such as Facet L, Regiment, or Postscript combined with Ricestar HT for the best barnyardgrass salvage option. However, the key to a season-long, successful weed control program is to start early with overlapping residual herbicides and timely postemergent applications to stay on top of problematic weeds before the grower is in a salvage-type situation. However, if there are delays in applications and a salvage situation occurs, there are options to provide sufficient barnyardgrass control. Growers and consultants should carefully assess each situation though and determine whether the added costs associated with these salvage treatments would be profitable in relation to the potential yield savings.

Acknowledgments

The authors would like to thank the Arkansas Rice Research and Promotion Board, the University of Arkansas System Division of Agriculture, and Gowan for their support of this research.

Literature Cited

Heap, I., 2022. The international survey of herbicide-resistant weeds. Accessed 4 Feb. 2022. Available at https://www.weedscience.org

Norsworthy, J.K., J.A. Bond, and R.C. Scott. 2013. Weed management practices and needs in Arkansas and Mississippi rice. Weed Technol. 27:623-630.

Table 1. Herbicide treatments in a study conducted at the University of Arkansas at Pine Bluff Small Farm Outreach Center, near Lonoke, Arkansas, in 2021.[a]

Treatment Number	Treatment Name	oz/ac
1	Nontreated control	
2	Ricestar HT	17
3	Ricestar HT	24
4	Ricestar HT	24
	Facet L	32
5	Ricestar HT	24
	Facet L	43
6	Ricestar HT	24
	Postscript	6.0
7	Ricestar HT	24
	Clincher	15
8	Ricestar HT	24
	Clincher	25
9	Ricestar HT	24
	Regiment	0.6
10	Clincher	32
	Facet L	32
11	Ricestar HT	24
	Facet L	32
	Regiment	0.5

[a] A surfactant was used in all treatments where labels dictated.

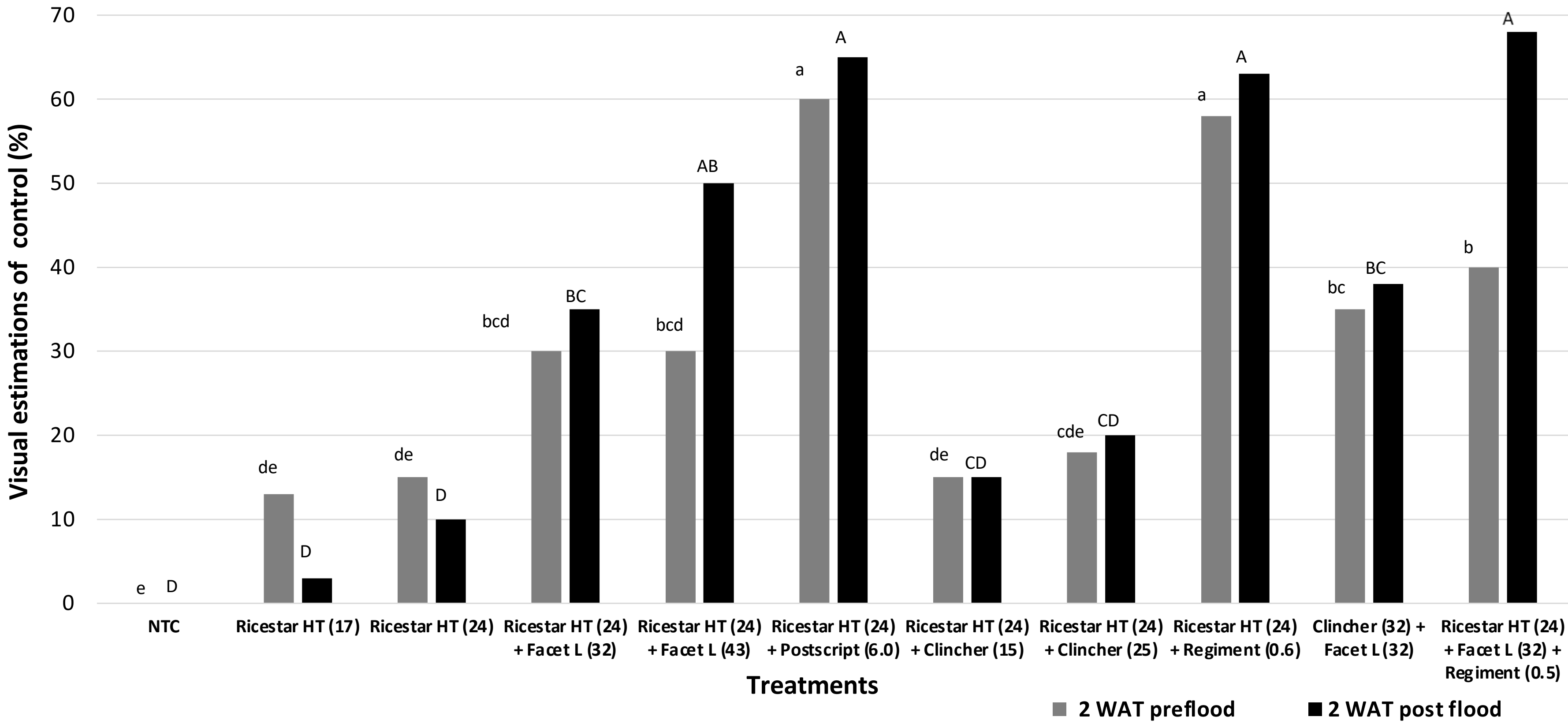

Fig. 1. Barnyardgrass (*Echinochloa crus-galli*) control at 2 weeks after treatment (WAT) for preflood and postflood applications. Treatments within rating timing depicted with the same letter are not different according to Fisher's protected least significant difference a = 0.05.

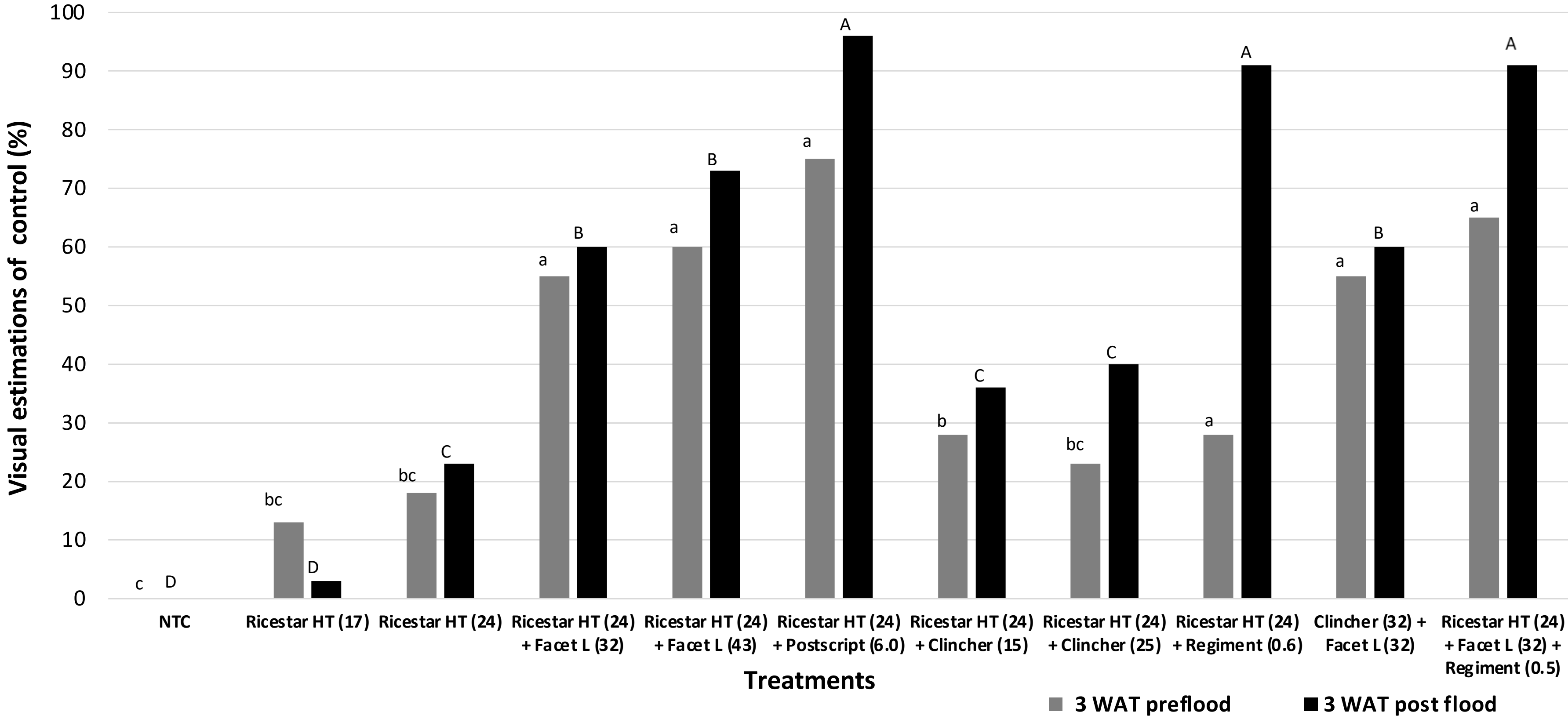

Fig. 2. Barnyardgrass (*Echinochloa crus-galli*) control at 3 weeks after treatment (WAT) for preflood and postflood applications. Treatments within rating timing depicted with the same letter are not different according to Fisher's protected least significant difference a = 0.05.

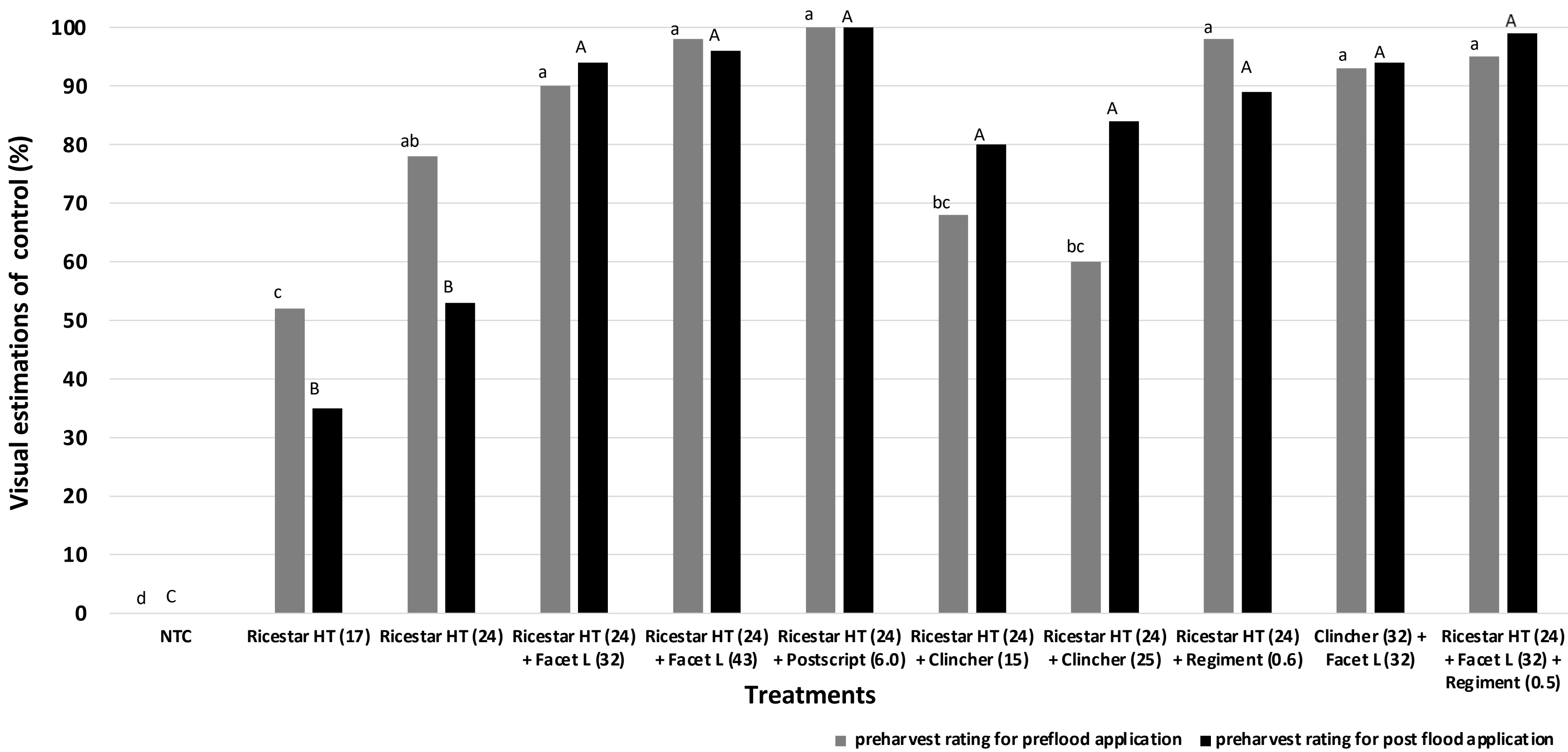

Fig. 3. Barnyardgrass (*Echinochloa crus-galli*) control at preharvest for preflood and postflood applications. Treatments within rating timing depicted with the same letter are not different according to Fisher's protected least significant difference a = 0.05.

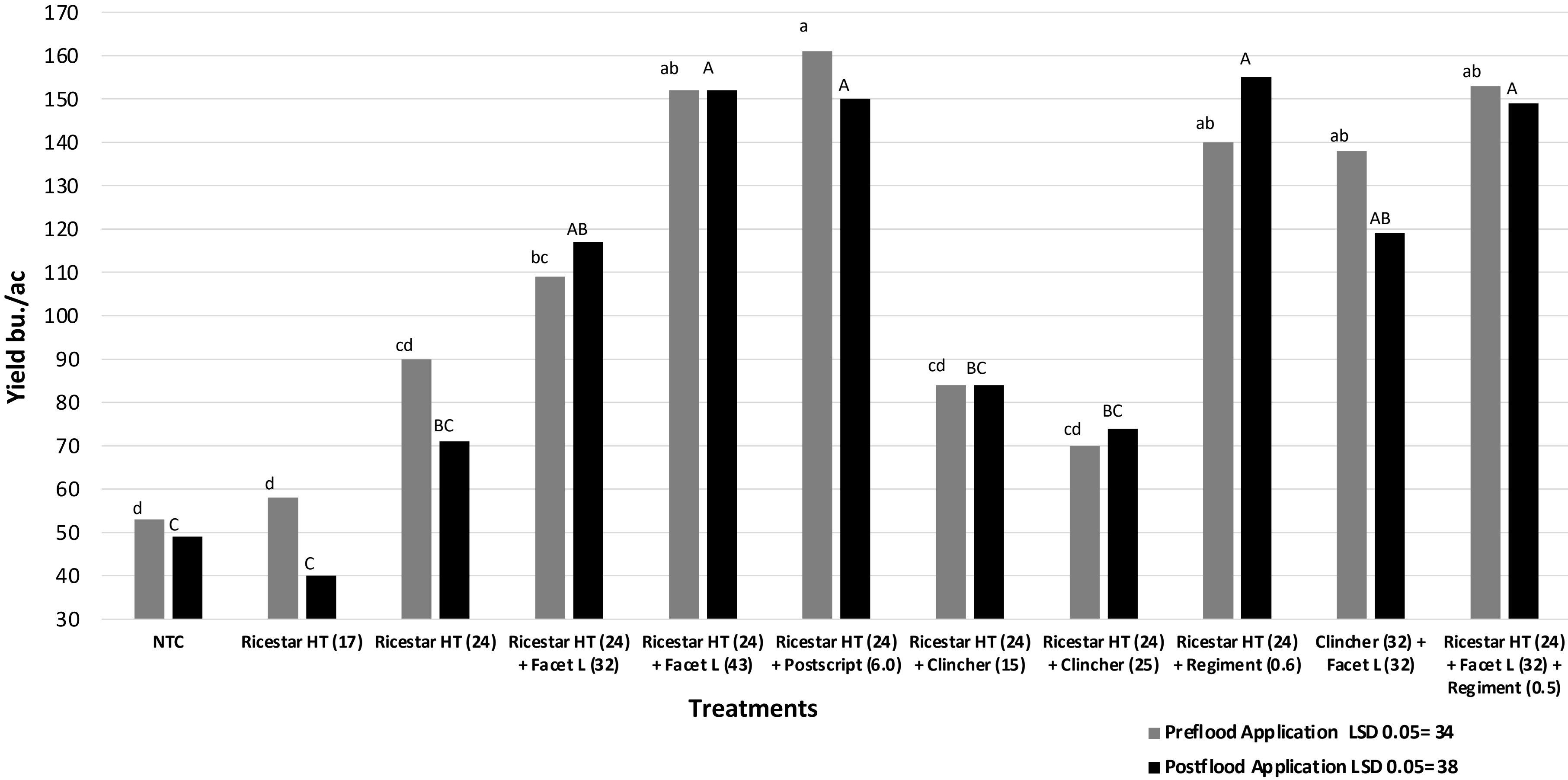

Fig. 4. Rough rice yields in bushels per acre (bu./ac). Treatments depicted with the same letter are not different according to Fisher's protected least significant difference test at a = 0.05.

The Possibility of Remote Rice Weed Seedling Detection with Drones

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Abstract

Weeds compete with rice for resources, and suboptimal management can result in significant yield losses. Proper weed seedling identification with adequate herbicide application timeliness are required to develop effective weed control strategies. With a gradually decreasing barrier to entry, stakeholders are gaining interest in using drone remote sensing to facilitate scouting and optimize strategic planning. However, remote rice weed detection presents unique challenges, and rice growers will only fully benefit from available technologies if provided with decision-support systems that meet their specific needs. Often, assumptions are made on the type and quality of information that can be extracted from drone images without proof that such data can, in fact, be collected. The objective of this study was to determine if rice weed seedlings could be identified in raw drone images collected before flood. Remote sensing and ground-truth data were collected in 6 locations with different weed species, rice growth stages, and weed seedling sizes. Weed seedlings were counted in the field and in drone images collected at different flight altitudes. Data were analyzed to compare the number of weed seedlings seen in the drone images to the number of weed seedlings found in the field. Results demonstrated that it was not always possible to distinguish all rice weed seedlings in the collected images independently from image resolution. When possible, drone images needed to be collected at a very low altitude (less than 5 ft) using typical prosumer drone remote sensing equipment. The findings provided a better understanding of the possibilities and limitations of drone remote rice weed seedling detection.

Introduction

Weeds are one of the most problematic and adaptable pests worldwide, and effective weed control is required to minimize losses from weed interference (Oerke, 2006). Among existing weed control technologies, chemical methods are most widely used for their high efficacy and simplicity of use (Shaner and Beckie, 2013). However, destabilizing factors such as new herbicide resistances and changes in growing conditions due to climate change require growers to implement new weed control strategies that are as adaptive as the weed species they target. Weed management in rice (*Oryza sativa*) is particularly difficult as flooding makes herbicide applications and field scouting more difficult and expensive.

In the past few decades, stakeholders' approach to rice weed control has progressed with the emergence of new challenges and technologies. At the operational level, integrated weed management (IWM) practices and site-specific technologies are increasingly used to reduce input use and minimize the emergence of new herbicide resistance (Esposito et al., 2021). At the strategic level, drone remote sensing facilitates scouting and helps producers optimize IWM strategies (Hunt and Daughtry, 2017). Today, drone remote sensing is recognized as a viable weed monitoring option in row crops, but remote rice weed detection presents unique challenges that are difficult to overcome.

Before flood, grass weeds have thin, elongated leaves, which can only be identified at very high spatial resolution. In the first few weeks after flood establishment, standing water covers weeds and creates reflection that significantly reduces image quality (Ogunti et al., 2018). For these reasons, the top three rice weeds of major economic importance: barnyardgrass (*Echinochloa crus-galli*), sprangletop (*Leptochloa* spp.), and red rice (*Oryza sativa*) are difficult to distinguish from rice until the crop reaches its reproductive stage. This compels us to find innovative ways to interpret and use the collected imagery. Fortunately, there is no one-size-fits-all solution to remote weed detection, and different approaches can be used to automate image processing and generate data that is relevant to the producers' specific needs, objectives, and technological capabilities.

The creation of a decision-support system that generates practical rice weed management information could help Arkansas producers maximize benefits from available drone remote sensing and weed control technologies. However, the development of such a system is not straightforward because of the number of parameters and complexity of interactions coming into play. Iterative approaches that involve stakeholders are most likely to result in the development of a tool that will be easily adopted and have a long-term, significant, and positive impact at the production scale. Success is contingent on our ability to properly assess needs and technological capabilities, but assumptions are often made on the type and quality of information that can be extracted from drone imagery. The objective of this study was to determine if rice weed seedlings can be identified within raw drone images collected before flood.

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

Procedures

Drone remote sensing and ground-truth data were collected in the spring of 2021 using small-plot rice weed herbicide control experiments located at the University of Arkansas System Division of Agriculture's Pine Tree Research Station in Colt (sites A and B), Rice Research and Extension Center in Stuttgart (sites C to E), and Lonoke Extension Center in Lonoke (site F). The experimental locations represented a wide range of herbicide-based weed control programs, including no-herbicide control plots and a mixture of hybrid and pure-line rice cultivars planted using the recommendations provided in the Arkansas Rice Production Handbook (Hardke, 2020). All experiments were managed using a delayed-flood production system, and different weed species representation and variability were observed between sites (Tables 1 and 2). In each location, eight to twelve 4 ft^2 quadrats built out of PVC pipes were placed in plots with different weed densities ranging from 4 to 82 seedlings/ft^2 (Table 3). Drone imagery was captured using a DJI Phantom 4 Pro V2.0 (DJI, Nanshan, Shenzen, China) unmanned aerial system equipped with a Red, Green, Blue (RGB) camera. Images were collected at different altitudes ranging from 3 to 400 ft. The raw image spatial resolution was computed as the ratio between the quadrat dimensions (2 × 2 ft) and the number of pixels representing them. Because different cameras create images with different resolutions at a given flight altitude, raw image resolution will be used as a reference throughout this manuscript. The resolution of the collected raw images ranged from 0.01 in./px at 3 ft to 1.57 in./px at 400 ft. Weed counts and composition by species, by quadrat were collected in the raw images and in the field for ground-truthing.

Statistical analysis was computed to compare the number of weed seedlings identified in the raw images with the number of weed seedlings found in the field (all species combined). Preliminary observations indicated that the percentage of weed seedlings identified in the raw images decreased exponentially with decreasing image resolution, and the data were modeled on the non-linear, exponential decay model described in Eq. 1:

$$R = \frac{N_{img}}{N_{gt}} = A + (R_0 - A) \times e^{-\alpha \times GSD} \quad \text{Eq. 1}$$

where *R* is the percentage of weed seedlings identified in a quadrat in a raw image, N_{img} is the number of weed seedlings identified in a quadrat in a raw image, N_{gt} is the number of weed seedlings identified in a quadrat in the field, *A* is the horizontal asymptote, α is the rate of decay, *GSD* is the image spatial resolution in in./px, and R_o is the value of *R* assuming GSD = 0. Separate analyses were conducted for each quadrat, and the optimum image resolution was calculated from the non-linear, exponential decay model parameters using Eq. 2:

$$GSD_{opt} = -\frac{1}{\alpha} \cdot ln\left(\frac{100\% - A}{R_0 - A}\right) \quad \text{Eq. 2}$$

where GSD_{opt} is the optimum image resolution, α is the rate of decay, *A* is the horizontal asymptote, and R_o is the value of *R,* assuming *GSD* = 0. At the optimum image resolution, 100% of the weed seedlings counted in a quadrat in the field were identified within the collected raw imagery. All data analysis was computed in R (R Core Team, 2022).

Results and Discussion

The optimum image resolution was greater than zero in 11 out of 59 quadrats (Table 4). In the other quadrats, it was practically not possible to identify all weed seedlings from the drone raw images regardless of the flight altitude (Figs. 1 and 2). Among the 11 quadrats listed above, the optimum image resolution was greater than zero in 12 of 12 (100%), 0 of 8 (0%), 3 of 10 (30%), 4 of 10 (40%), 1 of 10 (10%), and 2 of 9 (22%) quadrats in sites A to F, respectively. Such uneven distribution between sites indicated that the possibility of using drone imagery to identify rice weed seedlings before flood establishment may depend on rice weed species representation, rice growth stage, and weed seedling size. Grass weed seedlings were particularly difficult to identify and distinguish from rice seedlings. The optimum image resolution did not vary with weed density in a location.

Practical Applications

The maximum optimum image resolution was 0.04 in./px. This corresponded to a flight altitude lower than 5 ft using typical prosumer drone remote sensing equipment and lower than 15 ft using the best available cameras. Collecting drone imagery at such low altitudes throughout a cropping system is not practical, but drone imagery collected before flood could be used to monitor rice weed seedling development in specific areas of a field (e.g., along levees or field borders) where increased rice weed seedling emergence is anticipated. Future research is needed to determine under which circumstances we can expect to distinguish most rice weed seedlings within the collected imagery and to evaluate the possibility of using cameras mounted on agricultural implements to identify rice weed seedling emergence hotspots before flood at a larger scale than what may be accomplished using drones. Furthermore, it is worth noting that the findings from this study are limited to drone imagery collected before flood, and additional research should be conducted to determine if drone remote sensing can be used to monitor weed development during and after flood. Findings would provide a better understanding of available technological capabilities. Ultimately, research will be needed to automate drone image processing and develop a decision-support system that provides Arkansas rice producers with relevant information to optimize IWM.

Acknowledgments

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

Literature Cited

Esposito M., M. Crimaldi, V. Cirillo, F. Sarghini, and A. Maggio, 2021. Drone and sensor technology for sustainable weed management: a review. Chem. Biol. Technol. Agric. 8, 18. https://dx.doi.org/10.1186/s40538-021-00217-8

Hardke, J.T., 2020. Rice production handbook. Little Rock, AR; University of Arkansas Cooperative Extension Service Print Media Center.

Hunt, E.R. and C.S.T. Daughtry, 2017. What good are unmanned aircraft systems for agricultural remote sensing and precision agriculture? Intl. J. Remote Sensing 39:15-16.

Ogunti E.O., F.K. Akingbade, A. Segun, and O. Oladimeji, 2018. Decision support system using mobile applications in the provision of day-to-day information about farm status to improve crop yield. Per. Engin. Nat. Sci. 6:89-99.

Oerke E.C, 2006. Crop losses to pests. J. Agric. Sci. 144:31-43.

R Core Team, 2022. R: a language and environment for statistical computing. R Foundation for Statistical Computing. Accessed 21 February 2022. Available at https://www.R-project.org/

Shaner D.L., and H.J. Beckie, 2013. The future for weed control and technology. Pest Manag. Sci. 70:1329-1339.

Table 1. Experimental locations and rice weed species found at the University of Arkansas System Division of Agriculture's Pine Tree Research Station (PTRS), Rice Research and Extension Center (RREC), and Lonoke Extension Center (LEC).

Site	Location	County	Primary Weed Species[a]	Secondary Weed Species
A	PTRS	St. Francis	BYG, RR	HS, YNS, eclipta
B	PTRS	St. Francis	BYG, RR	HS, YNS, eclipta
C	RREC	Arkansas	BYG, RR, HS, YNS	BLSG, BYG, P
D	RREC	Arkansas	BYG, RR, HS, YNS	BLSG, BYG, PA
E	RREC	Arkansas	BYG, RR, HS, YNS	BLSG, BYG, PA
F	LEC	Lonoke	SGT	BYG, HS

[a] BYG, Barnyardgrass (*Echinochloa crus-galli);* RR, Red rice (*Oryza sativa*); HS, Hemp Sesbania (*Sesbania herbacea*); YNS, Yellow nutsedge (*Cyperus esculentis*); BLSG, Broadleaf signalgrass (*Urochloa platyphylla*); PA, Palmer amaranth (*Amaranthus palmeri*); SGT, Sprangletop (*Leptochloa* spp.).

Table 2. Data collection date and assessment of rice growth stage and weed seedling sizes in the selected sites at the University of Arkansas System Division of Agriculture's Pine Tree Research Station (PTRS), Rice Research and Extension Center (RREC), and Lonoke Extension Center (LEC).

Site	Data Collection Date	N_q[a]	Rice Growth Stage	Weed Seedling Size (range)
A	05/25/2021	12	V2	Seedling to 2.0 in.
B	06/03/2021	8	V2/3	Seedling to 4.0 in.
C	06/14/2021	10	V4	Seedling to 6.0 in.
D	06/14/2021	10	V4	Seedling to 6.0 in.
E	06/15/2021	10	V4/5	Seedling to 6.0 in.
F	06/23/2021	9	V4	0.5 to 6.0 in.

[a] N_q indicates the number of quadrats.

Table 3. Weed density per quadrat in the selected sites at the University of Arkansas System Division of Agriculture's Pine Tree Research Station (PTRS), Rice Research and Extension Center (RREC), and Lonoke Extension Center (LEC).

Site	1	2	3	4	5	6	7	8	9	10	11	12
	---------------------------- Weed density per quadrat (weed seedlings/ft^2) ----------------------------											
A	4	4	4	5	6	7	7	7	8	9	13	15
B	7	9	9	19	27	29	71	72	-	-	-	-
C	5	5	10	12	17	25	27	29	30	40	-	-
D	42	42	54	55	65	70	70	72	72	73	-	-
E	12	14	16	17	24	24	24	26	28	42	-	-
F	17	21	27	29	35	51	52	68	82	-	-	-

Table 4. Optimum raw image resolution per quadrat in the selected sites *at* the University of Arkansas System Division of Agriculture's Pine Tree Research Station (PTRS), Rice Research and Extension Center (RREC), and Lonoke Extension Center (LEC).

Site	1	2	3	4	5	6	7	8	9	10	11	12
	----------------------------Optimum image resolution per quadrat (in./px)----------------------------											
A	0.04	0.02	0.03	0.02	0.02	0.01	0.03	0.02	0.01	0.01	0.03	0.01
B	<0	<0	<0	<0	0.00	<0	<0	<0	-	-	-	-
C	0.01	<0	0.00	0.00	0.02	<0	<0	0.00	0.02	<0	-	-
D	0.00	0.01	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.01	-	-
E	0.00	0.01	<0	0.00	<0	<0	<0	<0	<0	<0	-	-
F	0.00	0.00	0.01	0.00	0.01	<0	<0	0.00	0.00	-	-	

Quadrats where the optimum resolution was greater than 0 were identified using light grey.

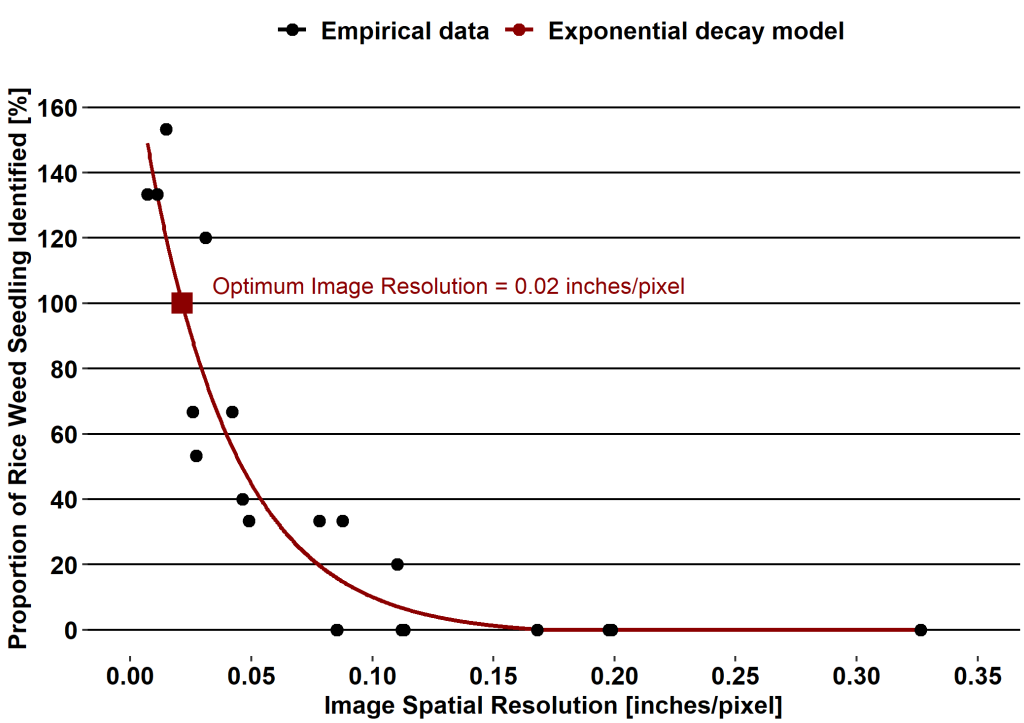

Fig. 1. The exponential decay model used to represent the empirical data collected in site A, quadrat 2. The optimum image resolution is represented using a red filled square.

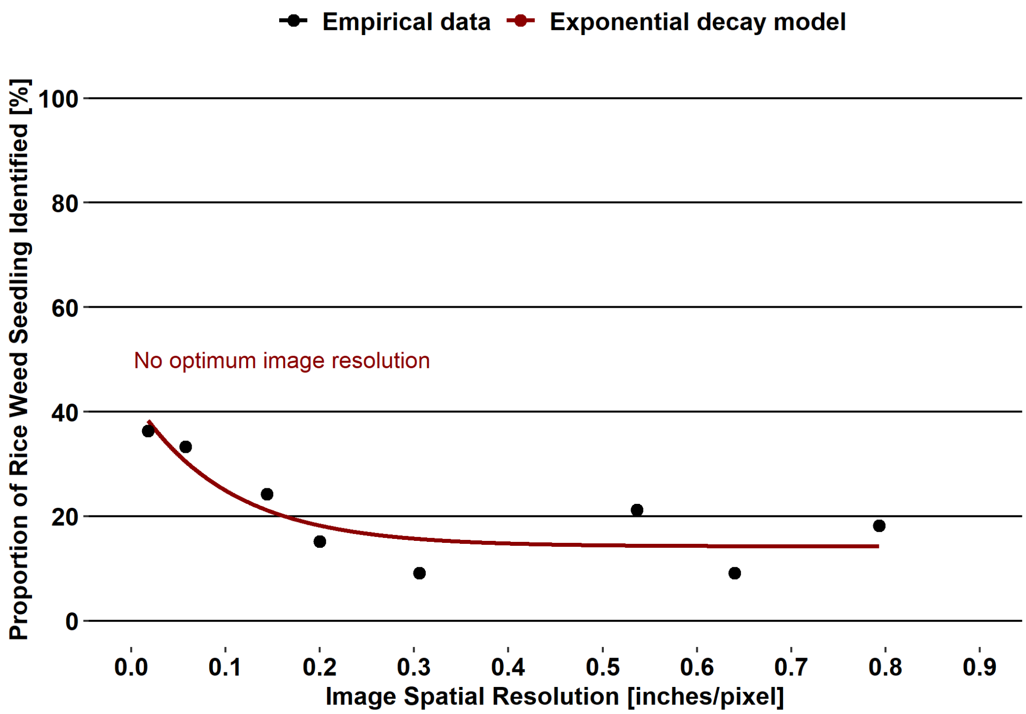

Fig. 2. The exponential decay model used to represent the empirical data collected in site B, quadrat 2. There was no optimum image resolution for this quadrat and location.

Effect of Sublethal Rate of Glyphosate on Provisia Rice Tolerance to Quizalofop

N. Godara,[1] J.K. Norsworthy,[1] L.T. Barber,[2] and T.R. Butts[2]

Abstract

Provisia (quizalofop-resistant) rice technology became commercially available for Mid-south growers in 2018 and was followed by injury to Provisia cultivars from postemergence applications of quizalofop. Rice is grown in close association with glyphosate-resistant corn, cotton, and soybean, increasing the risk of injury to rice through glyphosate drift. Field experiments were conducted in 2021 at Colt and Keiser, Arkansas, to determine if a sublethal rate of glyphosate interacts with sequential quizalofop applications to increase the risk for injury to Provisia rice cultivar PVL02 compared to applications of quizalofop alone. Experiments were implemented as a split-plot design, with location as a whole-plot factor and herbicide treatment (glyphosate followed by initial quizalofop application at 10-, 7-, 4-, and 0-day intervals and glyphosate applied alone at the same 10-, 7-, 4-, and 0-day intervals) as a split-plot factor. Glyphosate was applied at 0.08 lb ae/ac, 1/12.5X of the labeled use rate in soybean, and sequential quizalofop applications were at the recommended use rate of 0.1 lb ai/ac applied at the 2-leaf stage, followed by the 5-leaf stage. At 28 days after treatment (DAT), glyphosate followed by initial quizalofop at 0-day interval caused 19 percentage points more injury than glyphosate applied alone at the 0-day interval regardless of location. In addition, glyphosate followed by quizalofop at the 0-day interval had a higher glyphosate concentration in leaf tissue samples than glyphosate applied alone at the 0-day interval when sampled at 7 days after treatment for both locations. Furthermore, rough rice grain yield was reduced by 34 percentage points when glyphosate application was followed by quizalofop application at 0-day interval compared with glyphosate applied alone at Colt, Arkansas. Overall, glyphosate followed by quizalofop applications exacerbates injury over sequential quizalofop application alone or glyphosate exposure alone, and as the timing interval between exposure to sublethal glyphosate and quizalofop application shortens, the detrimental effect on Provisia rice increases.

Introduction

Provisia® rice is a non-genetically modified herbicide-resistant technology developed using traditional breeding techniques, allowing for postemergence applications of quizalofop, an acetyl CoA carboxylase (ACCase)-inhibiting herbicide for managing acetylate synthase (ALS)-resistant barnyardgrass [*Echinochloa crus-galli* (L.) P. Beauv.] and weedy rice (*Oryza sativa* L.), along with annual and perennial grass weed control (Barber et al., 2021; Guice et al., 2015). Provisia rice technology constituted 2.7% of the total area planted with rice in Arkansas in the growing season of 2020 due to limited availability and would increase exponentially in upcoming growing seasons (Hardke, 2021; Roma-Burgos et al., 2021). Conventional rice acreage is increasing in close association with glyphosate-resistant crop production systems and is highly susceptible to injury from glyphosate drift. Previous research reported that sublethal glyphosate rates caused significant injury and yield reductions ranging from 18% to 89% at two- to three-leaf to booting rice stages when 1/12.5X rate of glyphosate was applied (Kurtz and Street, 2003).

It was hypothesized that the preexposure to sublethal glyphosate rates would increase the risk for injury to Provisia rice over applications of quizalofop alone. The objective of this research was to determine if rice exposure to a sublethal glyphosate rate interacts with sequential quizalofop applications to aggravate the risk for injury to Provisia rice compared to applications of quizalofop alone or glyphosate exposure alone.

Procedures

Field experiments were conducted at the University of Arkansas System Division of Agriculture's Pine Tree Research Station, Colt, Arkansas, and at the Northeast Research and Extension Center, Keiser, Arkansas, in 2021. The experiment was implemented as a split-plot arrangement and replicated four times. The whole-plot factor was the location (Keiser, Colt), and the split-plot factor was herbicide treatment (glyphosate followed by initial quizalofop application at 10-, 7-, 4-, and 0-day intervals; glyphosate applied alone at the same 10-, 7-, 4-, and 0-day intervals; sequential quizalofop applications, and a nontreated control). The Provisia cultivar PVL02 was planted into 6 ft wide by 17 ft long plots at a depth of 0.5 in. with a seeding rate of 22 seeds per ft of drilled row. Glyphosate was applied at 0.08 lb ae/ac, 1/12.5X of the recommended use rate in soybean. Sequential applications of Provisia herbicide (quizalofop) at a labeled use rate of 0.1 lb ai/ac were made at the 2-leaf rice stage, followed by a second application at the 5-leaf rice stage before flooding. A 1% v/v crop oil concentrate was added to each quizalofop application. Herbicide treatments were made using a CO_2-pressurized backpack sprayer calibrated to deliver 10 gal/ac at 3 mph with AIXR110015 spray nozzles.

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Data collected consisted of visible estimates of crop injury, rice groundcover, glyphosate concentration, 50% heading dates, and rough rice grain yield. Visible estimations of injury were rated on a 0 to 100 scale, with 0 being no injury and 100 being crop death at 7, 14, 21, 28, and 35 days after treatment (DAT). Drone images were taken at 7, 14, 21, 28, and 35 DAT and subjected to Field Analyzer to estimate the relative groundcover. Five plants were harvested at the 7 days after glyphosate treatment from each plot and sent to Mississippi State Chemical Laboratory, Starkville, Mississippi, to determine the glyphosate concentration in plant tissue samples. The day when rice reached 50% heading was recorded. Plots were harvested for yield using a small-plot combine, and rough rice grain yield was adjusted to 12% moisture. All data were analyzed using SAS 9.4 and subjected to analysis of variance. All means were separated using Fisher's protected least significant difference test ($\alpha = 0.05$). For injury and groundcover response variables, rating timing was considered a repeated-measure variable that allowed for comparisons across rating timing and included in the treatment structure as a fixed effect.

Results and Discussion

Glyphosate followed by initial quizalofop application at a 0-day interval caused 19 percentage points greater injury than glyphosate applied alone at the 0-day interval before initial quizalofop application timing when evaluated at 28 DAT, regardless of location (Table 1). Glyphosate, when followed by initial quizalofop application at a 4-day interval, caused 10 percentage points more injury compared to glyphosate applied alone at 4-days prior to initial quizalofop averaged over both locations at 28 DAT. No differences in injury were observed between glyphosate followed by initial quizalofop at 7- and 10-day intervals and glyphosate applied alone at 7- and 10-day intervals before initial quizalofop, irrespective of the location. There was minimal (<10%) injury caused by sequential quizalofop applications to the Provisia cultivar averaged over locations (Table 1). Glyphosate application in closer intervals to quizalofop applications caused more injury than glyphosate and sequential quizalofop applications alone.

There was a 42% reduction in relative groundcover when glyphosate was followed by initial quizalofop at a 0-day interval compared to glyphosate alone at a 0-day interval at Colt at 35 DAT (Table 2). Additionally, higher glyphosate accumulation was observed in plant tissue samples when glyphosate was followed by initial quizalofop at 0- and 4-day intervals than glyphosate applied alone at 0- and 4-day intervals when evaluated at 7 DAT (Table 3). Furthermore, minimal glyphosate accumulation was observed in sequential quizalofop treatment and nontreated check at both locations attributed to environmental contamination through glyphosate drift (Table 3). The severity of damage to Provisia rice cultivar PVL02 increased at Colt, Arkansas, compared to Keiser, Arkansas, due to cloudy and wet weather conditions during application timing.

There was no significant delay in heading observed between glyphosate followed by initial quizalofop application at 10-, 7-, 4-, and 0-day intervals compared with glyphosate applied alone at 10-, 7-, 4-, and 0-day intervals before initial quizalofop timing (Table 3). Glyphosate followed by initial quizalofop at a 0-day interval reduced rough rice yields by 34 percentage points compared with glyphosate alone at a 0-day interval before quizalofop at the Colt, Arkansas location; however, no differences in yield were observed when glyphosate followed by quizalofop at 10-, 7-, and 4-day intervals compared with glyphosate alone at 10-, 7-, and 4-day intervals before quizalofop at either location. Overall, glyphosate followed by quizalofop applications increases the risk for injury to the PVL02 Provisia cultivar over sequential quizalofop applications alone or glyphosate alone. Reducing the timing interval between sublethal exposure to glyphosate and quizalofop applications intensifies the detrimental effect.

Practical Applications

Research showed that preexposure to sublethal drift of glyphosate increases the likelihood of injury to Provisia rice from sequential quizalofop applications. Glyphosate accumulation was also observed in tissue samples collected from Provisia applications only and nontreated check plots, indicating that glyphosate preexposure is extremely likely in conventional rice hectares. However, either the glyphosate drift rate was low, or the timing interval between glyphosate and standard herbicides was not close enough to stimulate crop response.

Acknowledgments

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Literature Cited

Barber L.T., T.R. Butts, K. Cunningham, G. Selden, J.K. Norsworthy, N.R. Burgos, and M. Bertucci. 2021. MP44 Recommended Chemicals for Weed and Brush Control, MP 44. University of Arkansas System Division of Agriculture Cooperative Extension Service, Little Rock, Ark.

Guice J., C. Youmans, A. Rhodes, J. Schultz, S. Bowe, G. Armel, and J. Harden. 2015. Provisia rice system: Weed management strategies for rice. Proc. South. Weed Sci. Soc. 68:197.

Hardke J.T. (2021) Trends in Arkansas Rice Production. *In*: J. Hardke, X. Sha, and N. Bateman (eds). B.R. Wells Arkansas Rice Research Studies 2020. Arkansas Agricultural Experiment Station Research Series 676:11-18.

Kurtz M.E. and J.E. Street. 2003. Response of rice (*Oryza sativa*) to glyphosate applied to simulate drift. Weed Technol., 17(2):234–238.

Roma-Burgos N., T.R. Butts, I. Werle, S. Bottoms, and A. Mauromoustakos. 2021. Weedy rice update in Arkansas, USA, and adjacent locales. Weed Sci. 69(5):514-525.

Table 1. Injury to Provisia rice cultivar PVL02 from herbicide treatments at different rating timings, averaged over both locations at the University of Arkansas System Division of Agriculture's Pine Tree Research Station, Colt, Arkansas, and at the Northeast Research and Extension Center, Keiser, Arkansas in 2021.†

	Rating timing				
Herbicide treatment‡	7 DAT	14 DAT	21 DAT	28 DAT	35 DAT
	--------------------	--------------------	%	--------------------	--------------------
G alone at 10-day	26 e-i	29 efg	21 e-l	19 f-l	17 h-n
G alone at 7-day	9 n-r	13 j-o	8 o-s	6 p-s	4 st
G alone at 4-day	17 i-n	17 g-n	17 i-n	11 l-p	10 m-q
G alone at 0-day	29 e-h	67 bc	71 b	58 cd	52 d
G fb IQ at 10-day interval	26 e-i	31 ef	17 h-n	23 e-j	18 g-m
G fb IQ at 7-day interval	12 k-p	12 k-p	4 q-t	10 m-q	5 q-t
G fb IQ at 4-day interval	23 e-j	25 e-i	25 e-i	21 e-k	15 i-o
G fb IQ at 0-day interval	33 e	78 ab	86 a	77 b	71 bc
Sequential quizalofop	4 srt	5 q-t	2 ut	1 u	1 u

† Means followed by the same letter are not different based on Fisher's protected least significant difference test at α = 0.05.

‡ fb = followed by; G = Glyphosate; IQ = Initial Quizalofop; DAT = days after treatment.

Table 2. Relative groundcover percentage compared to the nontreated check at different rating timings after herbicide treatment at the University of Arkansas System Division of Agriculture's Pine Tree Research Station, Colt, Arkansas, and at the Northeast Research and Extension Center, Keiser, Arkansas in 2021.†

		Rating timings				
Location	Herbicide treatment‡	7 DAT	14 DAT	21 DAT	28 DAT	35 DAT
		--------------------	--------------------	%	--------------------	--------------------
Keiser						
	G alone at 10-day	23.3 o-n	39.8 f-n	88.5 a-h	96.5 a-f	94.9 a-f
	G alone at 7-day	58.4 a-k	73.7 a-i	97.5 a-f	97.6 a-f	102 a-e
	G alone at 4-day	74.1 a-i	53.4 b-m	95.6 a-f	103 a-e	104 a-e
	G alone at 0-day	97.7 a-f	25.6 k-o	66.8 a-j	96.6 a-f	98 a-f
	G fb IQ at 10-day interval	11 op	21.5 on	75.7 a-i	93.4 a-g	97.5 a-f
	G fb IQ at 7-day interval	60 a-k	63.7 a-j	101 a-e	102 a-e	101 a-e
	G fb IQ at 4-day interval	87.2 a-i	35.8 i-n	99.4 a-e	107 a-e	105 a-e
	G fb IQ at 0-day interval	109 a-e	36.7 h-n	51.1 b-n	98.7 a-e	108 a-e
	Sequential quizalofop	114 abc	87.6 a-i	99.4 a-e	103 a-e	103 a-e
Colt						
	G alone at 10-day	46.2 c-n	45.3 d-n	110 a-d	80.5 a-i	106 a-e
	G alone at 7-day	82.4 a-i	95.2 a-f	136 a	87.2 a-i	91 a-h
	G alone at 4-day	63.8 a-j	79.4 a-i	110 a-d	72.8 a-i	90.4 a-h
	G alone at 0-day	71 a-i	21.7 omn	27.1 j-o	7.5 qp	43.9 e-n
	G fb IQ at 10-day interval	64.5 a-j	76.8 a-i	117 ab	88.9 a-h	103 a-e
	G fb IQ at 7-day interval	87.6 a-i	83.8 a-i	112 abc	98.1 a-f	94.1 a-f
	G fb IQ at 4-day interval	54.5 b-l	37.7 g-n	95.1 a-f	81.3 a-i	107 a-e
	G fb IQ at 0-day interval	99.5 a-e	68.6 a-i	3.6 qr	0.05 s	2.3 r
	Sequential quizalofop	83.9 a-i	88.3 a-i	124 ab	85.6 a-i	100 a-e

† Means followed by the same letter are not different based on Fisher's protected least significant difference test at α = 0.05.

‡ fb = followed by; G = Glyphosate; IQ = Initial Quizalofop; DAT = days after treatment.

Table 3. Glyphosate concentration, relative heading, and relative yield compared to nontreated check of Provisia rice cultivar PVL02 at the University of Arkansas System Division of Agriculture's Pine Tree Research Station, Colt, Arkansas, and at the Northeast Research and Extension Center, Keiser, Arkansas in 2021.[†]

Location	Herbicide treatment[‡]	Glyphosate	Relative	Relative yield
		ppb	days	%
Keiser				
	Nontreated check	113.3 ghi	-	-
	G alone at 10-day	190.2 d-g	5 bc	89.9 ab
	G alone at 7-day	137 f-i	1 efg	93.7 ab
	G alone at 4-day	415.4 bc	3 c-f	88.8 ab
	G alone at 0-day	148.1 f-i	8 a	81.4 ab
	G fb IQ at 10-day interval	168 e-h	6 ab	90.1 ab
	G fb IQ at 7-day interval	190.6 d-g	3 def	103.8 ab
	G fb IQ at 4-day interval	544 bc	5 bc	104 ab
	G fb IQ at 0-day interval	316.1 cde	8 a	93.2 ab
	Sequential quizalofop	86.6 hi	1 efg	93.3 ab
Colt				
	Nontreated check	263.3 c-f	-	-
	G alone at 10-day	80.2 hij	-1 g	91.4 ab
	G alone at 7-day	270.1 c-f	0 g	92.3 ab
	G alone at 4-day	39.8 jk	1 fg	108.1 a
	G alone at 0-day	825.2 b	4 b-e	67.2 b
	G fb IQ at 10-day interval	70.3 ij	-1 g	76.5 b
	G fb IQ at 7-day interval	365.9 cd	0 g	104.4 a
	G fb IQ at 4-day interval	503.5 bc	1 fg	94.3 ab
	G fb IQ at 0-day interval	2078.4 a	5 bcd	33.3 c
	Sequential quizalofop	26.5 k	0 g	106.1 a

[†] Means followed by same letters within the same column are not significantly different based on Fisher's protected least significant difference with $\alpha = 0.05$.

[‡] fb = followed by; G = Glyphosate; IQ = Initial Quizalofop.

A Two-Year Review: Evaluating the Tolerance of FullPage™ Rice to Acetolactate Synthase (ALS) Inhibiting Herbicides

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

Abstract

Sulfonylurea herbicides have been found effective in controlling glyphosate-resistant Italian ryegrass [*Lolium perenne* L. ssp. *multiflorum* (Lam.) Husnot] in fields planted to corn (*Zea mays* L.). FullPage™ rice (*Oryza sativa* L.) was released in 2020 on a limited basis and has been found to provide increased tolerance to imazethapyr and imazamox herbicide. Two experiments were conducted on a silt loam soil in Tillar, Arkansas, in 2020 and 2021 to determine the tolerance of FullPage™ rice to sulfonylurea herbicides applied preemergence (PRE) and postemergence (POST). Treatments consisted of Resolve Q (rimsulfuron + thifensulfuron) at 1.25 and 0.625 oz/ac, Steadfast Q (nicosulfuron + rimsulfuron) at 1.5 and 0.75 oz/ac, and Accent Q (nicosulfuron) at 0.75 and 0.375 oz/ac. When applied PRE, minimal levels of stunting were observed from most treatments within two weeks after application. When applied POST, crop stunting, chlorosis, leaf malformation, and necrosis were observed with most treatments, with crop stunting being more prevalent throughout the season. In 2020, within 14 days after the POST application (DAPOST), all treatments exhibited varying levels of stunting and chlorosis, with both rates of Steadfast Q resulting in the highest levels of injury. Similarly, by 35 DAPOST, the rates of Steadfast Q continued to exhibit observable levels of stunting. Regardless of the levels of phytotoxicity earlier in the growing season, rice yields were comparable across all treatments when compared to the weed-free check. In 2021, both rates of Resolve Q and Steadfast Q exhibited 8% to 23% stunting at 14 DAPOST. By 45 DAPOST, Steadfast Q at 1.5 oz/ac resulted in a significant delay in heading compared to the weed-free check, in addition to a significant yield reduction. These data suggest that when applied before rice planting or at planting, sulfonylurea herbicides may be beneficial in controlling herbicide-resistant Italian ryegrass. Although minimal yield reduction was observed when these herbicides were applied POST, significant levels of phytotoxicity were observed from all treatments.

Introduction

In recent years, Italian ryegrass [*Lolium perenne* L. ssp. *multiflorum* (Lam.) Husnot.] has been a prevalent early-season competitor to crops across the mid-South, including rice (*Oryza sativa* L.), with increased resistance development to some acetolactate synthase (ALS) inhibitors, ACCase-inhibiting herbicides, and glyphosate (Bond et al., 2014). Previous research has observed that the use of Group 15 herbicides is effective in controlling Italian ryegrass when applied in the fall; however, they are not considered a viable option due to the increased herbicide carryover to subsequently planted rice crops (Lawrence et al., 2018). Rimsulfuron- and nicosulfuron-containing products have been used to control Italian ryegrass at planting or before planting corn (Butts et al., 2020). In 2020, FullPage™ rice was introduced as improved imidazolinone (IMI)-tolerant hybrid cultivars and may offer some tolerance to sulfonylurea herbicides due to its dual gene IMI resistance. The objective of this research was to determine the tolerance of FullPage™ rice to preemergence (PRE) and postemergence (POST) applications of sulfonylurea herbicides.

Procedures

Two experiments were conducted on silt loam soil in Tillar, Arkansas, in 2020 and 2021. In 2020, FullPage™ RT7321FP was drilled at 30 lb/ac, whereas, in 2021, FullPage™ RT7521FP was drilled at 30 lb/ac, with all experiments set up as a randomized complete block design, with four replications and plot sizes of 6.33 ft by 30 ft. In all experiments, sulfonylurea herbicide treatments were applied either PRE or POST on 4- to 5-leaf rice growth stage and consisted of Resolve Q® (rimsulfuron + thifensulfuron) at 1.25 and 0.625 oz/ac, Steadfast Q® (nicosulfuron + rimsulfuron) at 1.5 and 0.75 oz/ac, and Accent Q® (nicosulfuron) at 0.75 and 0.375 oz/ac. All treatments were applied with 0.25% v/v nonionic surfactant. Treatments were applied with a compressed air-pressurized tractor-mounted sprayer calibrated to deliver 12 gal/ac in 2020 and 15 gal/ac in 2021, using Teejet® AIXR 110015 nozzles. Visual phytotoxicity ratings were taken at 14 and 35 days after the POST application (DAPOST) and were compared to a weed-free check, in addition to a percent of rice-headed rating taken at 45 DAPOST in 2021. In all experiments, fertility

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and pest management practices were managed using University of Arkansas System Division of Agriculture recommendations. Rice yields were taken using a Kincaid 8XP plot combine on 13 October 2020 and on 14 October 2021. These data were subjected to an analysis of variance, and means were separated by Fisher's protected least significant difference with a *P*-value of 0.05.

Results and Discussion

2020 Results

Although slight levels of stunting were observed from most PRE-treatments up to two weeks after application, no differences in injury or yield reduction were observed throughout the season (data not shown). When applied POST, various types of phytotoxicity were observed, including stunting, chlorosis, leaf malformation (data not shown), and necrosis (data not shown). At 14 DAPOST, stunting was observed from Steadfast Q® at 0.75 and 1.5 oz/ac and Resolve Q® at 1.25 oz/ac, with 25%, 26%, and 13% stunting, respectively (Table 1). Additionally, chlorosis injury was comparable to stunting from both rates of Resolve Q® and Steadfast Q® (Table 1). By 35 DAPOST, both rates of Steadfast Q® continued to exhibit observable levels of stunting over that of other treatments (Table 2). Despite the observed injury earlier in the season, comparable yields were observed from all treatments, as well as the weed-free check ranging from 164 to 172 bu./ac (Table 4).

2021 Results

As in 2020, when applied PRE, minimal stunting was observed for a short period following application; albeit no significant injury or yield reductions were observed (data not shown). Stunting was observed at 14 DAPOST from the higher rates of Resolve Q and Steadfast Q, with 20% and 23% stunting, respectively (Table 1). Resolve Q at 1.25 oz/ac and Steadfast Q at 1.5 oz/ac exhibited chlorosis at 14 DAPOST, though it was not as severe as seen in 2020. By 35 DAPOST, little to no injury was observed from any treatment (Table 2). Steadfast Q at the high rate resulted in a lower yield compared to the weed-free check (Table 3). Similarly, when compared to the weed-free check, a delay in heading, albeit numerically different, was observed from Steadfast Q at 1.5 oz/ac by 45 DAPOST (Table 4).

Practical Applications

When applied at planting, applications of sulfonylurea herbicides caused little injury and no yield loss, which may allow for the possible use of these herbicides to control Italian ryegrass before or at planting with FullPage™ rice. When applied POST, phytotoxicity was observed within two weeks after the POST application. Additionally, these data suggest that some yield reduction may be observed from certain sulfonylurea herbicides. The difference in yield reduction between years may be a function of different rice cultivars. Further research needs to be conducted on varying soil types, especially soils with higher pH, in addition to different rice cultivars.

Acknowledgments

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Literature Cited

Bond, J.A., T.W. Eubanks, R.C. Bond, B.R. Golden, and H.M. Edwards. 2014. Glyphosate-resistant Italian ryegrass (*Lolium perenne* ssp. *multiflorum*) control with fall-applied residual herbicides. Weed Technol. 28:361-370.

Butts, T.R., A. McCormick, L.T. Barber, J.K. Norsworthy, and N.R. Burgos. 2020. Management of Italian ryegrass in Agronomic crops. Uni. Of Ark. FSA2191. https://www.uaex.uada.edu/publications/PDF/FSA2191.pdf

Lawrence, B.H., J.A. Bond, H.M. Edwards, B.R. Golden, G.B Montgomery, T.H. Eubanks, and T.W. Walker. 2018. Effect of fall-applied residual herbicides on rice and yield. Weed Technol. 32:526-531.

Table 1. FullPage™ rice stunting and chlorosis at 14 days after the postemergence application in experiments conducted on silt loam soil in Tillar, Arkansas in 2020 and 2021.

			2020		2021	
Treatments	Rate(s)	Application Timing	Stunting	Chlorosis	Stunting	Chlorosis
	oz/ac		---------------------------------	-----------%-----------	---------------------------------	
Weed-free check	---		0	0	0	0
Resolve Q	1.25	4- to 5-leaf rice	13	18	20	6
Steadfast Q	1.5	4- to 5-leaf rice	26	21	23	8
Accent Q	0.75	4- to 5-leaf rice	0	9	0	0
Resolve Q	0.625	4- to 5-leaf rice	0	15	13	0
Steadfast Q	0.75	4- to 5-leaf rice	25	24	8	3
Accent Q	0.375	4- to 5-leaf rice	0	3	0	0
LSD (*P* = 0.05)			6	7	7	6

Table 2. FullPage™ rice stunting at 35 days after the postemergence application in experiments conducted on silt loam soil in Tillar, Arkansas in 2020 and 2021.

			2020	2021
Treatments	Rate(s)	Application Timing	Stunting	Stunting
	oz/ac		--------------------%--------------------	
Weed-free check	---		0	0
Resolve Q	1.25	4- to 5-leaf rice	0	0
Steadfast Q	1.5	4- to 5-leaf rice	10	3
Accent Q	0.75	4- to 5-leaf rice	0	0
Resolve Q	0.625	4- to 5-leaf rice	0	0
Steadfast Q	0.75	4- to 5-leaf rice	10	0
Accent Q	0.375	4- to 5-leaf rice	0	0
LSD (P = 0.05)			5	2

Table 3. FullPage™ rice yields following the postemergence application in experiments conducted on silt loam soil in Tillar, Arkansas in 2020 and 2021.

			2020	2021
Treatments	Rate(s)	Application Timing	Yield	Yield
	oz/ac		--------------------bu./ac--------------------	
Weed-free check	---		167	141
Resolve Q	1.25	4- to 5-leaf rice	165	135
Steadfast Q	1.5	4- to 5-leaf rice	164	129
Accent Q	0.75	4- to 5-leaf rice	172	139
Resolve Q	0.625	4- to 5-leaf rice	167	136
Steadfast Q	0.75	4- to 5-leaf rice	169	140
Accent Q	0.375	4- to 5-leaf rice	165	138
LSD (P = 0.05)			12	10

Table 4. FullPage™ rice heading at 46 days after the postemergence application in 2021 in experiments conducted on silt loam soil in Tillar, Arkansas.

Treatments	Rate(s)	Application Timing	Heading
	oz/ac		%
Weed-free check			65
Resolve Q	1.25	4- to 5-leaf rice	54
Steadfast Q	1.5	4- to 5-leaf rice	39
Accent Q	0.75	4- to 5-leaf rice	59
Zest	0.67	4- to 5-leaf rice	74
Resolve Q	0.625	4- to 5-leaf rice	60
Steadfast Q	0.75	4- to 5-leaf rice	68
Accent Q	0.375	4- to 5-leaf rice	71
Zest	0.337	4- to 5-leaf rice	79
LSD (P = 0.05)			28

Evaluation of Benzobicyclon Rates for the Control of Amazon Sprangletop and Rice Flatsedge in a Flooded Environment

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

In a recent survey, Amazon sprangletop [*Diplachne panicoides* (J. Presl) Hitchc.] and rice flatsedge (*Cyperus iria* L.) were among the top problematic weeds in Arkansas rice acres. Benzobicyclon, a 4-hydroxyphenylpyruvate dioxygenase (HPPD)-inhibiting postflood herbicide, has recently been registered for use in Arkansas and has shown to provide broad-spectrum control of many aquatics, broadleaf, sedge, and grass weeds in rice. Two experiments were conducted in Tillar, Arkansas, to determine an effective rate of benzobicyclon to control Amazon sprangletop and rice flatsedge at varying growth stages. Both experiments were conducted in a randomized complete block design with four replications. Herbicide treatments consisted of benzobicyclon applied at 0.109, 0.218, and 0.328 lb ai/ac and tank-mixed with methylated seed oil concentrate at 1.0% v/v. Treatments were applied to rice flatsedge at 3 to 4 in., 6 to 8 in., and 12 to 18 in. in heights and to Amazon sprangletop at the 3 to 4 leaf, tillering and heading growth stages. At 7 days after application (DAA), no rate of benzobicyclon provided greater than 64% control of rice flatsedge. Control from all rates was less than 86% at the second height (6 to 8 in.) at 21 DAA. All rates of benzobicyclon provided greater than 98% control of rice flatsedge at the smallest height (3 to 4 in.) at 41 DAA. In the second experiment, benzobicyclon at 0.218 lb ai/ac provided greater than 90% control of Amazon sprangletop when applied to the 3 to 4 leaf timing at 21 DAA. Throughout the experiment, benzobicyclon at 0.328 lb ai/ac provided greater control of Amazon sprangletop when applied at the two smallest timings. Although little control was observed from any rate of benzobicyclon when applied to heading sprangletop, benzobicyclon at the highest rate did prohibit seedhead maturation. Based on these data, the use of benzobicyclon can be beneficial in controlling these problematic weeds.

Introduction

Amazon sprangletop [*Diplachne panicoides* (J. Presl) Hitchc.] and rice flatsedge (*Cyperus iria* L.) were listed among the top weeds of concern in Arkansas rice in a recent survey. Both species exhibit prolific growth and exert heavy competitiveness with the crop. Incorporating new herbicides into current rice herbicide programs may be beneficial in controlling problematic weeds in Mid-south rice acres (Norsworthy et al., 2013). Additionally, overreliance on acetolactate synthase-inhibiting, acetyl CoA carboxylase-inhibiting, and other commonly applied herbicide modes of action has resulted in the increasing development of resistance (Heap, 2022). Benzobicyclon, a Weed Science Society of America Group 27 (4-hydroxyphenylpyruvate dioxygenase (HPPD)-inhibiting postflood herbicide, has been shown to provide broad-spectrum control of many aquatics, broadleaves, grasses, and sedges (Komatsubara et al., 2009). The objective of this research was to determine an effective rate of benzobicyclon to control varying growth stages of Amazon sprangletop and rice flatsedge.

Procedures

Two experiments were conducted at Tillar, Arkansas, in a randomized complete block design with four replications. A simulated flooded environment, with a silty-clay loam soil placed into a plastic tote, was established. Each tote had a 17 gal capacity, with the dimensions of 22 in. in length, 17 in. in width, and 11 in. in height. Specimens of both weed species were transplanted to the totes at the 1 to 2 leaf growth stage, and a moderate flood was added and maintained in each tote throughout the experiments. Treatments consisted of benzobicyclon applied at 0.109, 0.218, and 0.328 lb ai/ac and tank-mixed with methylated seed oil concentrate at 1.0% v/v. Herbicide treatments were applied with a CO_2-pressurized backpack sprayer calibrated to deliver 15 gal/ac in volume, using Teejet AIXR 11002 nozzles. These treatments were applied to rice flatsedge at 3 to 4 in., 6 to 8 in., and 12 to 18 in. heights and to Amazon sprangletop at the 3 to 4 leaf, tillering and heading growth stages. Herbicide efficacy was visually evaluated in both experiments for control of Amazon sprangletop and rice flatsedge. These data were subjected to an analysis of variance, and means were separated by Fisher's protected least significant difference with a *P*-value of 0.05.

Results and Discussion

Regardless of the application timing, initial control of rice flatsedge was less than 64% from all benzobicyclon rates at 7 days after application (DAA) (Table 1). By 21 DAA, all rates of

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benzobicyclon provided greater than 81% control at the smallest growth stage (Table 2). As rice flatsedge heights increased, control from all rates was less than 86% at the 6 to 8 in. timing and less than 32% at the 12 to 18 in. timing. By 41 DAA, all rates of benzobicyclon provided greater than 98% control of rice flatsedge at the smallest height. Benzobicyclon at 0.218 and 0.328 lb ai/ac provided 98% and 96% control, respectively, when applied to 6 to 8 in. rice flatsedge (Table 3). In the second experiment, benzobicyclon at 0.109 lb ai/ac failed to provide greater than 74% control of Amazon sprangletop when applied to any growth stage (Table 4). As the benzobicyclon rate increased to 0.218 lb ai/ac, greater than 90% control of sprangletop was observed when applied to 3 to 4 leaf sprangletop by 21 DAA (Table 5) and to tillering sprangletop by 41 DAA (Table 6). Overall, greater control of Amazon sprangletop was observed from benzobicyclon at 0.328 lb ai/ac when applied at the 3 to 4 leaf and tillering timings throughout the experiment. Regardless of the herbicide rate, less than 34% control of Amazon sprangletop was observed when applied at the heading application time; albeit, blanking of seed-heads was observed from benzobicyclon at 0.328 lb ai/ac (Table 6).

Practical Applications

Based on these data, the use of benzobicyclon can be effective in controlling Amazon sprangletop and rice flatsedge in flooded rice herbicide programs. Benzobicyclon at all rates was effective in controlling rice flatsedge when applied to 3 to 8 in. in height. Regarding Amazon sprangletop, benzobicyclon was shown to be most effective when applied at 0.218 and 0.328 lb ai/ac to the early postemergence and tillering growth stages.

Acknowledgments

Special thanks to Gowan,® the University of Arkansas System Division of Agriculture, and the Arkansas Rice Check-off Program administered by the Arkansas Rice Research and Promotion Board.

Literature Cited

Heap, I. The International Herbicide-Resistant Weed Database. Online. Accessed: 9 February 2022. Available at www.weedscience.org

Komatsubara, K.I., K. Sekino, Y. Yamada, H. Koyanagi, and S. Nakahara. 2009. Discovery and development of a new herbicide, benzobicyclon. J. Pest. Sci. 34(2):113-114.

Norsworthy J.K., J. Bond, and R.C. Scott. 2013. Weed management practices and needs in Arkansas and Mississippi rice. Weed Technol. 27:623-630.

Table 1. Rice flatsedge control at 7 days after application in an experiment conducted at Tillar, Arkansas.

Treatment(s)	Rate	Application timing	Control
	lb ai/ac		---------%---------
Nontreated control	---		0
Benzobicyclon	0.109	3 to 4 in.	56
Benzobicyclon	0.218	3 to 4 in.	16
Benzobicyclon	0.328	3 to 4 in.	64
Benzobicyclon	0.109	6 to 8 in.	62
Benzobicyclon	0.218	6 to 8 in.	59
Benzobicyclon	0.328	6 to 8 in.	45
Benzobicyclon	0.109	12 to 18 in.	29
Benzobicyclon	0.218	12 to 18 in.	31
Benzobicyclon	0.328	12 to 18 in.	27
LSD (P = 0.05)			16

Table 2. Rice flatsedge control at 21 days after application in an experiment conducted at Tillar, Arkansas.

Treatment(s)	Rate	Application timing	Control
	lb ai/ac		---------%---------
Nontreated control	---		0
Benzobicyclon	0.109	3 to 4 in.	81
Benzobicyclon	0.218	3 to 4 in.	98
Benzobicyclon	0.328	3 to 4 in.	96
Benzobicyclon	0.109	6 to 8 in.	74
Benzobicyclon	0.218	6 to 8 in.	86
Benzobicyclon	0.328	6 to 8 in.	84
Benzobicyclon	0.109	12 to 18 in.	31
Benzobicyclon	0.218	12 to 18 in.	23
Benzobicyclon	0.328	12 to 18 in.	32
LSD (P = 0.05)			13

Table 3. Rice flatsedge control at 41 days after application in an experiment conducted at Tillar, Arkansas.

Treatment(s)	Rate	Application timing	Control
	lb ai/ac		---------%---------
Nontreated control	---		0
Benzobicyclon	0.109	3 to 4 in.	99
Benzobicyclon	0.218	3 to 4 in.	99
Benzobicyclon	0.328	3 to 4 in.	98
Benzobicyclon	0.109	6 to 8 in.	76
Benzobicyclon	0.218	6 to 8 in.	98
Benzobicyclon	0.328	6 to 8 in.	95
Benzobicyclon	0.109	12 to 18 in.	91
Benzobicyclon	0.218	12 to 18 in.	80
Benzobicyclon	0.328	12 to 18 in.	79
LSD (P = 0.05)			9

Table 4. Amazon sprangletop control at 7 days after application in an experiment conducted at Tillar, Arkansas.

Treatment(s)	Rate	Application timing	Control
	lb ai/ac		---------%---------
Nontreated control	---		0
Benzobicyclon	0.109	3 to 4 leaf	49
Benzobicyclon	0.218	3 to 4 leaf	65
Benzobicyclon	0.328	3 to 4 leaf	74
Benzobicyclon	0.109	Tillering	53
Benzobicyclon	0.218	Tillering	56
Benzobicyclon	0.328	Tillering	70
Benzobicyclon	0.109	Heading	0
Benzobicyclon	0.218	Heading	0
Benzobicyclon	0.328	Heading	0
LSD (P = 0.05)			

Table 5. Amazon sprangletop control at 21 days after application in an experiment conducted at Tillar, Arkansas.

Treatment(s)	Rate	Application timing	Control
	lb ai/ac		---------%---------
Nontreated control	---		0
Benzobicyclon	0.109	3 to 4 leaf	71
Benzobicyclon	0.218	3 to 4 leaf	98
Benzobicyclon	0.328	3 to 4 leaf	99
Benzobicyclon	0.109	Tillering	50
Benzobicyclon	0.218	Tillering	77
Benzobicyclon	0.328	Tillering	96
Benzobicyclon	0.109	Heading	17
Benzobicyclon	0.218	Heading	18
Benzobicyclon	0.328	Heading	20
LSD (P = 0.05)			15

Table 6. Amazon sprangletop control at 41 days after application in an experiment conducted at Tillar, Arkansas.

Treatment(s)	Rate	Application timing	Control
	lb ai/ac		---------%---------
Nontreated control	---		0
Benzobicyclon	0.109	3 to 4 leaf	34
Benzobicyclon	0.218	3 to 4 leaf	98
Benzobicyclon	0.328	3 to 4 leaf	99
Benzobicyclon	0.109	Tillering	54
Benzobicyclon	0.218	Tillering	96
Benzobicyclon	0.328	Tillering	99
Benzobicyclon	0.109	Heading	25
Benzobicyclon	0.218	Heading	27
Benzobicyclon	0.328	Heading	34
LSD (P = 0.05)			9

Absorption, Translocation, and Metabolism of Cyhalofop-Butyl (Clincher) and Quizalofop-ethyl (Provisia) 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

Managing emerged weeds that have evolved resistance to herbicides is a challenging task. From dose-response experiments conducted previously, we selected barnyardgrass [*Echinochloa crus-galli* (L.) P. Beauv] biotypes susceptible (S) and resistant (R) to three aryloxyphenoxypropionate herbicides, namely cyhalofop-butyl (CyB; Clincher), fenoxaprop-ethyl (FeE; Ricestar HT), and quizalofop-ethyl (QuE; Provisia). For these barnyardgrass biotypes, absorption, translocation, and metabolism of CyB and QuE were evaluated to confirm the presence of a non-target-site resistance mechanism. Absorption, translocation, and total metabolism of tested herbicides were similar for S and R biotypes. Significant differences between S and R barnyardgrass were observed in the production of active acid forms of each herbicide (cyhalofop-acid and quizalofop-acid). Production of cyhalofop-acid was less in R barnyardgrass (3% to 8%) for 24 h after herbicide application than in the S barnyardgrass (8% to 16%). Meanwhile, the production of quizalofop-acid was less in R barnyardgrass (0% to 14%) throughout the study period than in the S barnyardgrass (3% to 22%). Overall results show that a non-target-site resistance mechanism altering the production of acid herbicide forms may contribute at least partly to the resistance of the tested barnyardgrass biotypes to CyB and QuE.

Introduction

Barnyardgrass [*Echinochloa crus-galli* (L.) P. Beauv] is the most troublesome weed in Arkansas rice production (Norsworthy et al., 2013), and profitable rice agriculture relies on the use of herbicides for barnyardgrass control (Andres et al., 2013). However, the evolution of herbicide resistance in barnyardgrass makes its control more challenging. Herbicides that inhibit acetyl CoA carboxylase (ACCase) are classified as a Weed Science Society of America Group 1 and include three chemical families: aryloxyphenoxypropionate (FOP), cyclohexanedione (DIM), and phenylpyrazolin (DEN) (Takano et al., 2021). Based on a recent report (Heap, 2022), cases of barnyardgrass resistance to ACCase-inhibiting herbicides have been only associated with FOP herbicides such as cyhalofop-butyl (CyB), fenoxaprop-p-ethyl (FeE), and quizalofop-p-ethyl (QuE). In our dose-response experiments conducted previously, the evolution of cross-resistance to CyB, FeE, and QuE were confirmed in some of the barnyardgrass seed samples collected from mid-southern USA rice fields. In the present study, absorption, translocation, and metabolism experiments were performed to reveal the potential resistance mechanism of barnyardgrass biotypes resistant to CyB and QuE.

Procedures

Based on previous results of herbicide resistance screening and dose-response experiments conducted for > 300 barnyardgrass seed samples collected from mid-southern USA rice fields (data not shown), barnyardgrass biotypes susceptible (S) and resistant (R) to CyB, FeE, and QuE were selected and used for this study. The R barnyardgrass biotypes selected were previously confirmed for no mutations in DNA genes of ACCase proteins (data not shown).

Absorption and translocation experiments were conducted using phenyl ring-labeled carbon-14 ([^{14}C]) chemicals of CyB (Corteva Agriscience™, Indianapolis, Ind., USA) and QuE (BASF Co., Triangle Park, N.C., USA). Meanwhile, the metabolism experiment was performed using commercial products and non-radioactive standards of the herbicides. At the four-leaf stage, seedlings of each barnyardgrass biotype were sprayed with the commercial product CyB (0.3 lb ai/ac; Clincher® SF, Corteva Agriscience™) or QuE (0.1 lb ai/ac; Provisia®, BASF Co.). Subsequently, the second true leaf of the sprayed plants was treated twice with 1.00 kBq of each [^{14}C]-herbicide, and the treated plants were grown in a growth chamber with 86/77 °F day/night temperatures. Plant samples were collected from each barnyardgrass biotype 6, 12, 24, and 48 h after [^{14}C]-herbicide treatment, and the treated leaf was rinsed with 5 mL methanol. Additionally, the rinsed plants were sectioned into the treated leaf, untreated aboveground tissue, and belowground tissue and then combusted by a biological oxidizer. The treated leaf rinsates and oxidized tissue samples were analyzed by liquid scintillation counter. The absorption of herbicides was calculated by subtracting the [^{14}C]-activity analyzed from methanol rinsates of the treated leaf at each sampling time from the initially analyzed [^{14}C]-activity. Time-dependent translocation to each plant tissue was calculated as proportions of the [^{14}C]-activity measured in each tissue sample at each sampling time relative to the [^{14}C]-activity absorbed in each

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sampling time. Time-dependent metabolism of non-radioactive herbicides in barnyardgrass samples was analyzed for the entire plant tissue without dissection, and the parent compounds and active acid forms such as cyhalofop-acid (CyA) and quizalofop-acid (QuA) were quantified using a high-performance liquid chromatography−diode array detector (HPLC−DAD).

Statistical analysis for absorption, translocation, and metabolism test data was conducted using an authorized statistic software, 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 was applied to evaluate significant differences in analytical results between S and R biotypes at each sampling time.

Results and Discussion

Foliar absorption of CyB (88% to 98%) and QuE (84% to 95%) tended to increase over time and was similar for S and R barnyardgrass biotypes at each sampling time ($P > 0.05$) (Fig. 1). For both S and R biotypes, most of CyB (87% to 96%) and QuE (96% to 97%) absorbed were present in the treated leaf over the 48-h study period, and <13% translocated to other plant tissues (Fig. 2). Moreover, differences in translocation magnitudes observed between S and R biotypes at each sampling time were <2%. Thus, absorption and translocation were not influential factors that can confer the observed herbicide resistance to barnyardgrass. Likewise, total metabolism did not show differences between S and R biotypes over the entire study period (Fig. 3). Differences between S and R barnyardgrass biotypes were observed in residual magnitudes of active acid forms (i.e., CyA and QuA) converted enzymatically from the applied forms of each herbicide (Fig. 4). Following application with CyB (0.3 lb ai/ac), production of CyA was less in R barnyardgrass biotypes (3% to 8%) than in the S biotype (8% to 16%). Similarly, reduced production of QuA after QuE application (0.1 lb ai/ac) was also observed in the R biotypes (0% to 14%); QuA production in the S biotype ranged from 3% to 22%. The efficacy of pro-herbicides such as CyB and QuE containing an alkyl ester in the applied form can be closely associated with the extent to which they are converted to the active acid form in the weedy plant. Previous studies have reported that the resistance of some weed species to pro-herbicides such as imazamethabenz-methyl (Nandula et al., 2000), florpyrauxifen-benzyl (Hwang et al., 2021), and cyhalofop-butyl (Deng et al., 2021) can be attributed partially to reduced production and/or rapid degradation of the active acid form. Given these previous reports, reduced conversion to or rapid metabolism of acid herbicide forms observed in the present study may contribute at least partially to the resistance evolution to CyB and QuE in barnyardgrass.

Practical Applications

Overall results of the present study demonstrate that the evolution of CyB and QuE resistance in barnyardgrass is partially attributed to reductions in reduced production or rapid degradation of the acid forms CyA and QuA. These results are useful for finding solutions to mitigate or overcome barnyardgrass resistance to FOP herbicides and to obtain inspiration for the development of new herbicide actives.

Acknowledgments

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Literature Cited

Andres, A., G. Theisen, G. Concenço, and L. Galon. 2013. Herbicides - Current research and case studies in use (eds. Price, A., and Kelton, J.): Weed resistance to herbicides in rice fields in Southern Brazil. IntechOpen, pp. 3−25.

Deng, W., M. Yang, Y. Li, Z. Xia, Y. Chen, S. Yuan, and Q. Yang. 2021. Enhanced metabolism confers a high level of cyhalofop-butyl resistance in a Chinese sprangletop (*Leptochloa chinensis* (L.) Nees) population. Pest Manag. Sci. 77:2576−2583.

Heap, I., 2022. The International Herbicide-Resistant Weed Database. Accessed: 10 November 2021. Available at http://www.weedscience.org/Home.aspx

Hwang, J.I., J.K. Norsworthy, F. González-Torralva, G.L. Priess, L.T. Barber, and T.R. Butts. 2021. Non-target-site resistance mechanism of barnyardgrass [*Echinochloa crus-galli* (L.) P. Beauv] to florpyrauxifen-benzyl. Pest Manag. Sci. 78:287−295.

Nandula, V.K. and C.G. Messersmith. 2000. Mechanism of wild oat (*Avena fatua* L.) resistance to imazamethabenz-methyl. Pestic. Biochem. Physiol. 68:148−155.

Norsworthy, J.K., J. Bond, and R.C. Scott, 2013. Weed management practices and needs in Arkansas and Mississippi rice. Weed Sci. 27:623−630.

Takano, H.K., R.F.L. Ovejero, G.G. Belchior, G.P.L. Maymone, and F.E. Dayan, 2021. ACCase-inhibiting herbicides: mechanism of action, resistance evolution and stewardship. Sci. Agric. 78. https://dx.doi.org/10.1590/1678-992X-2019-0102

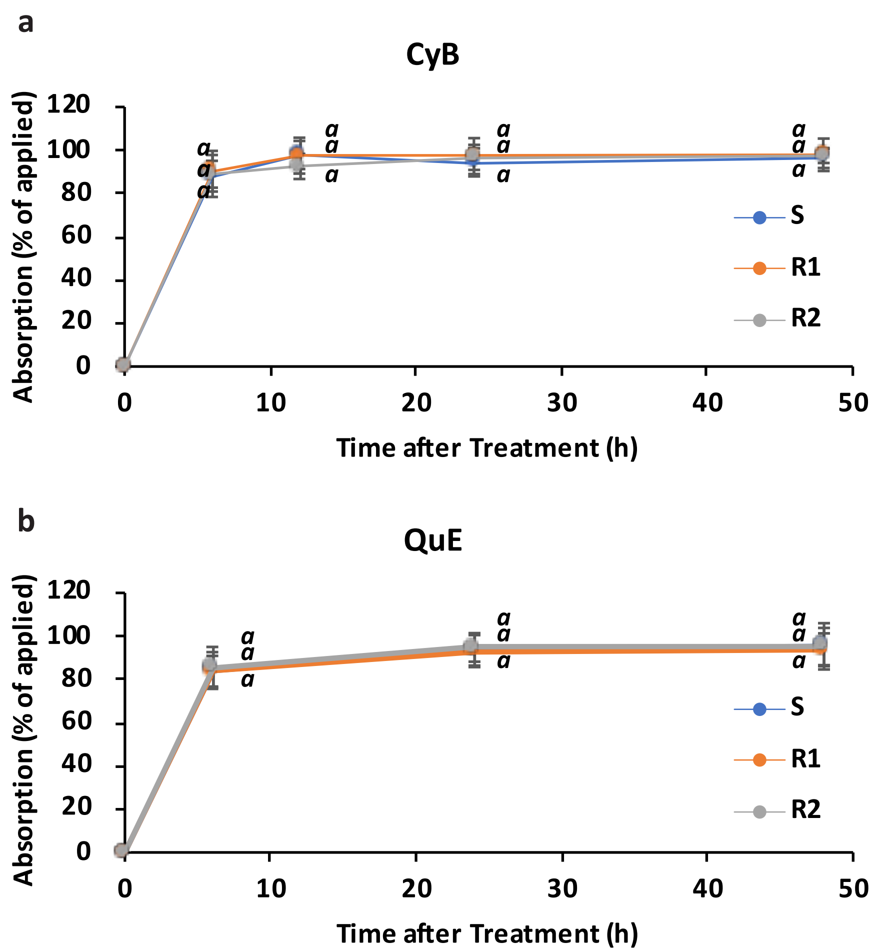

Fig. 1. Foliar absorption of (a) [^{14}C]-cyhalofop-butyl (CyB) and (b) [^{14}C]-quizalofop-p-ethyl (QuE) by susceptible (S) and two resistant (R1 and R2) barnyardgrass biotypes. Error bars represent standard deviations to mean values (*n* = 6). Based on Tukey's honestly significant difference test results, significant differences are indicated with different lowercase italic letters (*P* < 0.05).

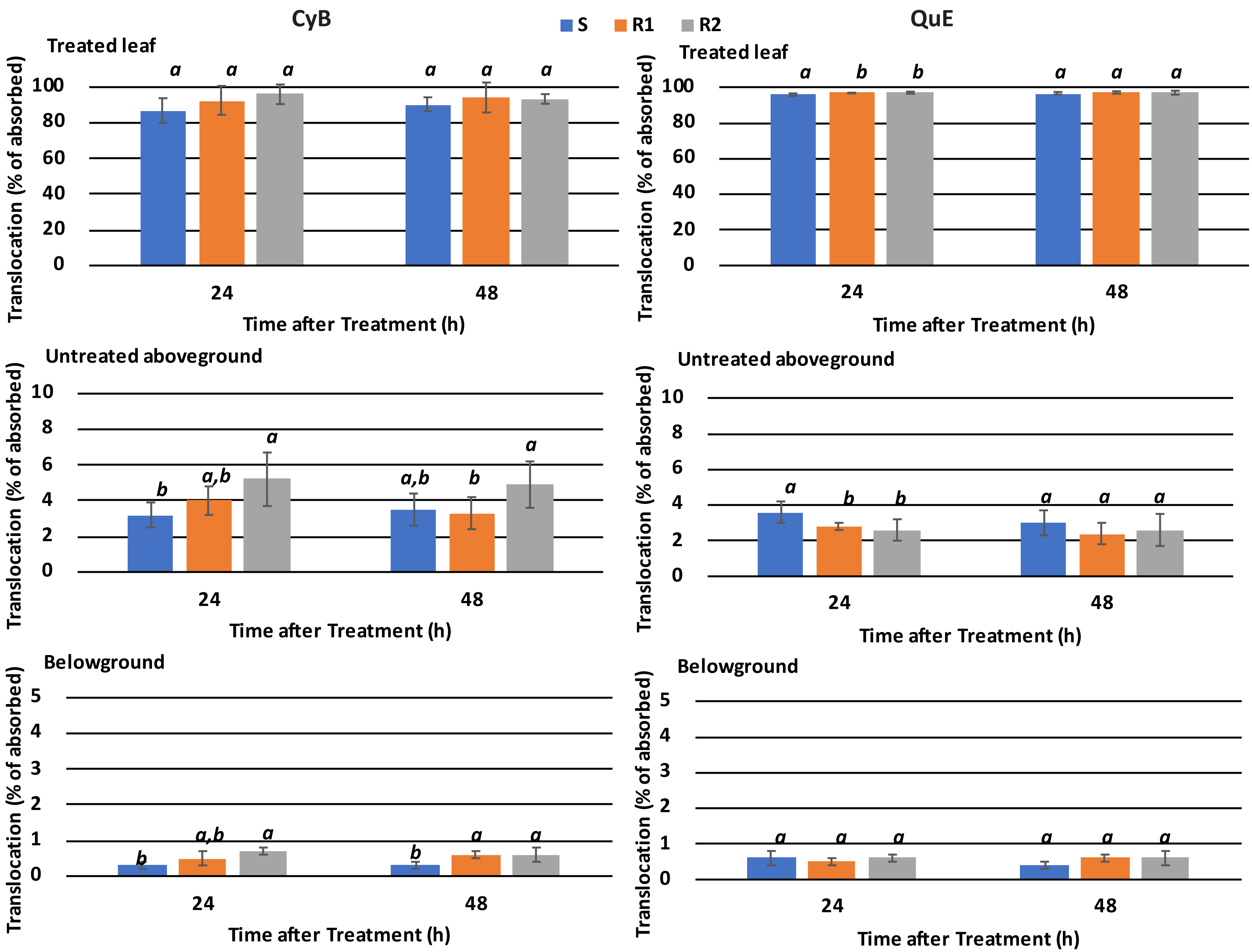

Fig. 2. Translocation of [^{14}C]-cyhalofop-butyl (CyB) and [^{14}C]-quizalofop-p-ethyl (QuE) absorbed in susceptible (S) and two resistant (R1 and R2) barnyardgrass biotypes. Error bars represent standard deviations to mean values (n = 6). Based on Tukey's honestly significant difference test results, significant differences are indicated with different lowercase italic letters ($P < 0.05$).

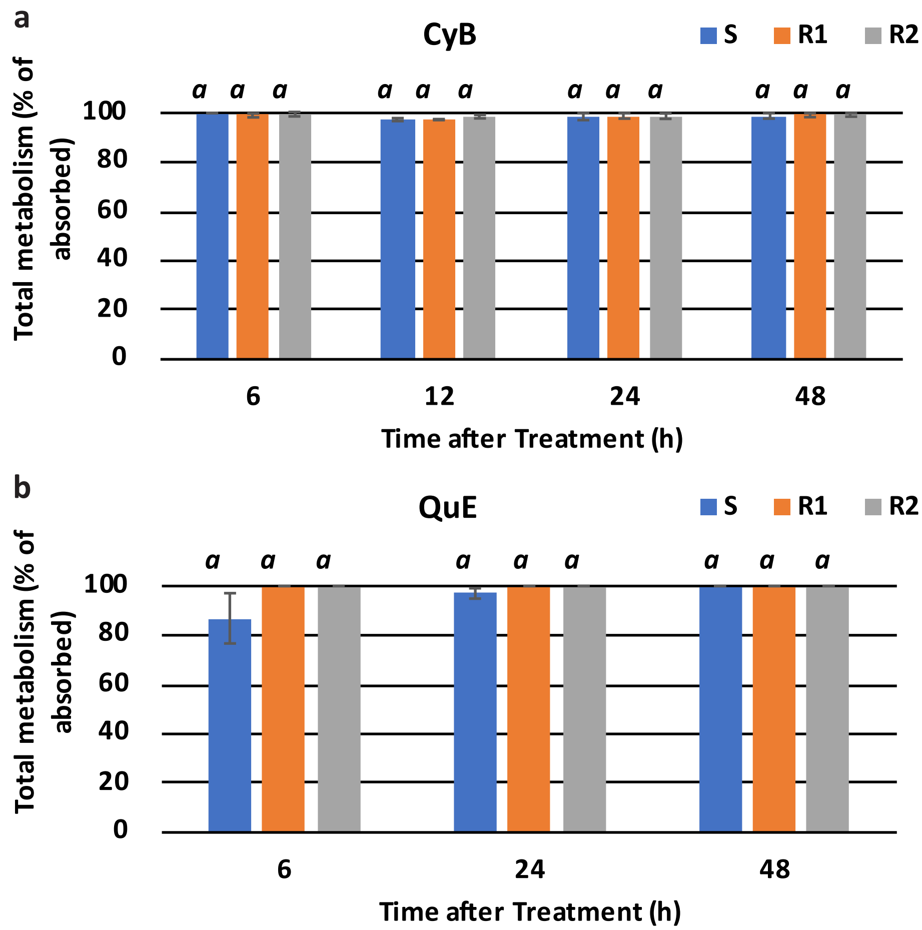

Fig. 3. Total metabolism of (a) cyhalofop-butyl (CyB) and (b) quizalofop-p-ethyl (QuE) absorbed in susceptible (S) and two resistant (R1 and R2) barnyardgrass biotypes. Error bars represent standard deviations to mean values (*n* = 6). Based on Tukey's honestly significant difference test results, significant differences are indicated with different lowercase italic letters (*P* < 0.05).

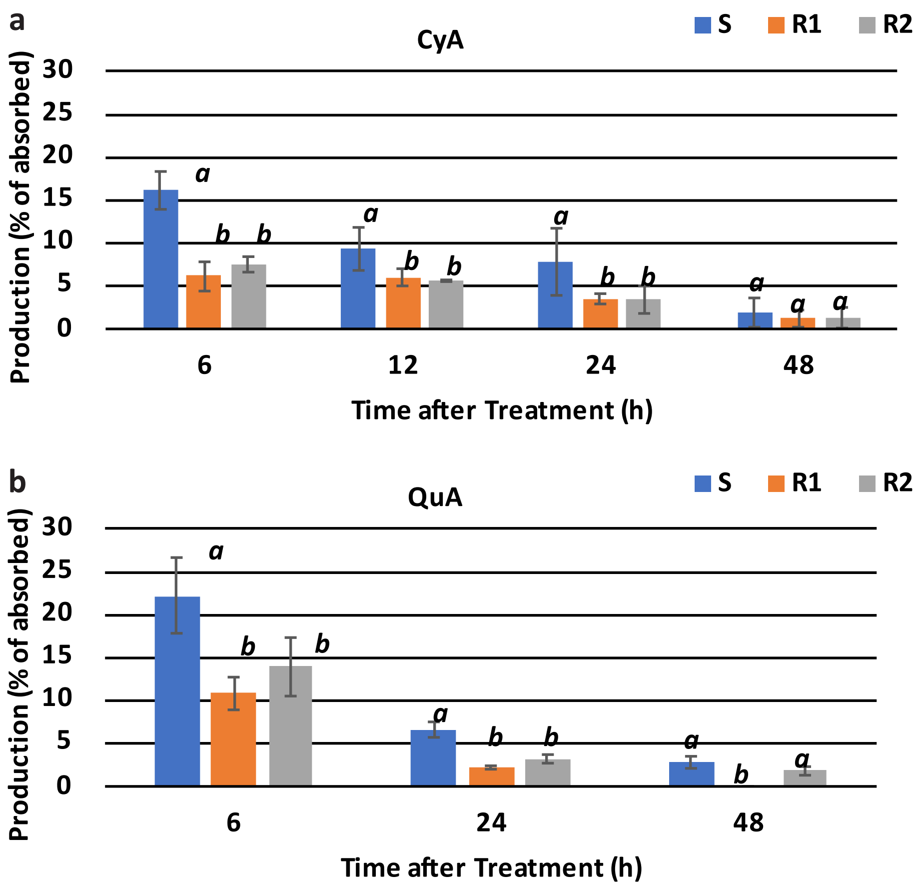

Fig. 4. Time-dependent production of active acid form metabolites, (a) cyhalofop-acid (CyA) and (b) quizalofop-acid (QuA), in susceptible (S) and two resistant (R1 and R2) barnyardgrass biotypes. Error bars represent standard deviations to mean values (*n* = 6). Based on Tukey's honestly significant difference test results, significant differences are indicated with different lowercase italic letters (*P* < 0.05).

Use of a Fenclorim Seed Treatment with Delayed Preemergence Applications of Microencapsulated Acetochlor on a Clay Soil

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Abstract

Warrant® is a microencapsulated (ME) formulation of the Weed Science Society of America's Group 15 herbicides, acetochlor, capable of controlling both grasses and small-seeded broadleaf weeds. Acetochlor is traditionally used in row crops such as corn, cotton, and soybean as a residual herbicide and is not currently labeled for use in rice. A fenclorim seed treatment combined with a delayed preemergence application timing can potentially reduce injury. In 2021, an experiment was conducted in Keiser, Arkansas to evaluate the effectiveness of acetochlor as Warrant for both weed control and injury to rice on a clay soil. The experiment involved three rates of acetochlor (1.12, 1.68, and 2.25 lb ai/ac), with and without a fenclorim seed treatment at (2.5 lb ai/1000 lb-seed). All applications occurred at a delayed preemergence application timing at 15 gallons per acre (GPA). Control of three problematic weeds (Palmer amaranth, horse purslane, and broadleaf signalgrass) and rice injury were rated at 28 days after treatment (DAT). Palmer amaranth control was numerically greatest when acetochlor was applied at 2.25 lb ai/ac (93%) but did not significantly differ from 1.68 lb ai/ac (83%). In terms of horse purslane and broadleaf signalgrass, weed control was the highest at a rate of 2.25 lb ai/ac at 75% and 88% respectively and was greater than both other rates of acetochlor. Injury to 'Diamond' rice was reduced with the use of a fenclorim seed treatment at acetochlor rates of 1.68 and 2.25 lb ai/ac when compared to those rates without a fenclorim seed treatment. Fenclorim as a seed treatment provides the opportunity for ME acetochlor to be safely used in a drill-seeded rice production system on a clay soil.

Introduction

Herbicide resistance is a rising problem in terms of weed control in rice production systems in Arkansas. Palmer amaranth [*Amaranthus palmeri* (S.) Watson] has shown resistance to multiple modes of action and is increasingly more difficult to control with traditional herbicides in rice production systems (Schwartz-Lazaro et al., 2017). A microencapsulated formulation (ME) of acetochlor, Warrant®, has been commonly used as a herbicide in corn, cotton, and soybean to control grasses and small-seeded broadleaf weeds (Barber et al., 2020). As a Weed Science Society of America's group 15 herbicide, acetochlor is a very long-chain fatty acid elongase inhibitor and is an effective residual herbicide capable of controlling emerging seedlings. Control of small-seeded broadleaf weeds and grasses makes acetochlor a possible fit for rice production systems. However, acetochlor formulated as an emulsified concentrate (EC) can cause severe injury to rice plants (Fogleman et al., 2019). With a ME formulation, acetochlor has the potential to cause reduced injury to rice plants due to the slow-release technology (Becher, 2010). Furthermore, with the use of fenclorim as a herbicide safener that has been previously used with pretilachlor in water-seeded rice, another degree of safening to herbicide applications of ME acetochlor is possible (Avent et al., 2020; Quadranti and Ebner, 1983).

Procedures

A field study was conducted in 2021 in Keiser, Arkansas, at the University of Arkansas System Division of Agriculture's Northeast Research and Extension Center to observe the effects of ME acetochlor on a clay soil. The purpose of this experiment was to evaluate an acetochlor rate response with fenclorim on a heavy clay soil. The experiment was designed as a two-factor factorial within a randomized complete block design. The two factors evaluated were acetochlor rates at (1.12, 1.68, and 2.25 lb ai/ac) and the presence and absence of a fenclorim seed treatment at 2.5 lb ai/1000 lb-seed. All herbicide applications occurred at a delayed preemergence application timing on 4 May with a CO_2-pressurized backpack sprayer at 15 GPA at 3 MPH. 'Diamond' rice was planted at 22 seeds per foot of row. Palmer amaranth, horse purslane, and broadleaf signalgrass control were evaluated at 28 days after treatment on a 0% to 100% scale, with 0% being no control and 100% being complete control. Rice injury was also evaluated at 28 days after treatment on a similar scale (0% being no visible injury and 100% being plant mortality). Data were subjected to analysis of variance, and means were separated using Tukey's honestly significant difference with ($\alpha = 0.05$) using JMP Pro 16.1.

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Results and Discussion

As acetochlor rate increased, injury to rice without the fenclorim seed treatment likewise increased, which coincides with previous literature (Fogleman et al., 2019). In the absence of the fenclorim seed treatment, injury increased from 9 to 33 and from 33% to 49% for acetochlor rates of 1.12, 1.68, and 2.25 lb ai ac-1, respectively. However, the fenclorim seed treatment reduced rice injury with 1.68 and 2.25 lb ai/ac, and overall, injury with fenclorim was <10%. Similar results showed fenclorim reducing injury to acetochlor applications and reduced stand loss (Avent, 2020). Acetochlor efficacy was significant in terms of weed control based on the increased rates of herbicide (Table 1). This result is similar to research conducted at the University of Arkansas System Division of Agriculture looking at a ME acetochlor at different rates and application timings (Norsworthy et al., 2019.) With a fenclorim seed treatment, injury to 'Diamond' rice did not differ among the three rates of acetochlor. Fenclorim had no effect on the efficacy of acetochlor in terms of weed control and was not considered a significant factor. The combination of herbicide rate and the use of fenclorim at 0 and 2.5 lb ai/1000 lb-seed showed substantial injury reduction to 'Diamond' rice. In terms of rice injury, the use of a fenclorim seed treatment had a significant effect on the reduction of injury at higher levels of acetochlor rate. When fenclorim was used, injury was reduced from 49% to 9% at the highest rate of acetochlor. Similarly, at a rate of 1.68 lb ai/ac, the presence of a fenclorim seed treatment reduced injury. Rice injury at the lowest rate of acetochlor was not significantly affected by the presence of a fenclorim seed treatment (Table 2).

In terms of Palmer amaranth control, as the acetochlor rate increased, Palmer amaranth control generally increased. From 1.12 to 1.68 lb ai/ac, control increased from 64% to 83%, respectively (Table 3). Additionally, acetochlor at 2.25 lb ai/ac provided comparable Palmer amaranth control as acetochlor at 2.25 lb ai/ac. For horse purslane, the lowest rate of acetochlor provided 33% control. At an acetochlor rate of 1.68 and 2.25 lb ai/ac, horse purslane control increased to 59% and 75%, respectively. A similar trend was observed for broadleaf signalgrass control. Broadleaf signalgrass control with acetochlor at 1.12 lb ai/ac was 39% with an increase to 77% when the rate was increased to 1.68 lb ai/ac. At a rate of 2.25 lb ai/ac, control of broadleaf signalgrass was again increased to 88%, showing an increase in control as acetochlor rate was increased. Overall, the highest level of weed control for horse purslane and broadleaf signalgrass occurred at the highest rate of acetochlor. This response is expected as weed control is typically higher at increased rates of herbicide. While the high rate of acetochlor provided effective weed control, the injury observed to cultivated rice was the highest at this rate.

In terms of rice injury, the use of a fenclorim seed treatment had a significant effect on the reduction of injury at higher levels of acetochlor rate. When fenclorim was used, injury was reduced from 49% to 9% at the highest rate of acetochlor. Similarly, at a rate of 1.68 lb ai/ac, the presence of a fenclorim seed treatment reduced injury from 33% to 3%. Rice injury at the lowest rate of acetochlor was not significantly affected by the presence of a fenclorim seed treatment (Table 2).

While rice injury was lowest at an acetochlor rate of 1.12 lb ai/ac, weed control at this same rate was also the lowest. The ideal combination of maintaining a high level of weed control while keeping rice injury below 10% would be acetochlor at a rate of 2.25 lb ai/ac in conjunction with a fenclorim seed treatment at 2.5 lb of ai/1000 lb-seed.

Practical Applications

Warrant, a ME acetochlor formulation, is not labeled for use in rice production in any U.S. region, but use of the herbicide would offer an additional control option for some weeds without requiring a seed trait when used in conjunction with a fenclorim seed treatment. With the reduction in acetochlor injury provided by a fenclorim seed treatment, Warrant can be safely applied at a delayed preemergent application timing while continuing to provide effective weed control of key problematic weeds in a rice production system. By adding a group 15 herbicide in acetochlor, farmers would have an alternative site of action to spray on weeds that are resistant to currently labeled herbicides in rice production systems.

Acknowledgments

Support of weed science research in rice by the Arkansas Rice Research and Promotion Board is appreciated. The University of Arkansas System Division of Agriculture also supported this research.

Literature Cited

Avent T.H., J.K. Norsworthy, C.B. Brabham, L.B. Piveta, and M.C. Castner. 2020. Evaluation of a seed treatment for safening rice to rates of soil-applied acetochlor. *In*: K.A.K. Moldenhauer, B. Scott, and J. Hardke (eds.) B.R. Wells Arkansas Rice Research Studies 2019. Arkansas Agricultural Experiment Station Research Series 667:120-122. Fayetteville.

Barber T.L., T.R. Butts, K. Cunningham, G. Selden, J.K. Norsworthy, N.R. Burgos, and M. Bertucci. 2020. MP44: Recommended chemicals for weed and brush control. University of Arkansas System Division of Agriculture, Cooperative Extension Service. 193 p

Becher D.Z., inventor; Monsanto Technology LLC, assignee. 2010. February 13. Encapsulation of herbicides to reduce crop injury. International patent 2010,09370,A3.

Fogleman, M., J.K. Norsworthy, T. Barber, and E. Gbur. 2019. Influence of Formulation and Rate on Rice Tolerance to Early-Season Applications of Acetochlor. Weed Technology 33:239–245

Schwartz-Lazaro L.M., J.K. Norsworthy, R.C. Scott, and T.L. Barber. 2017. Resistance of two Arkansas Palmer amaranth populations to multiple herbicide sites of action. Crop Protection, 96;158-163.

Quadranti M. and L. Ebner. 1983. Sofit, a new herbicide for use in direct-seeded rice (wet-sown rice). pp. 405–412 in 9th Asian-Pacific Weed Science Society Conference. Philippines.

Table 1. Analysis of variance table with *P*-values for weed control and rice injury 28 days after treatment in a field study at the University of Arkansas System Division of Agriculture's Northeast Research and Extension Center in Keiser, Arkansas.

	Weed control			
Effect	Palmer amaranth	Horse purslane	Broadleaf signalgrass	Rice Injury
	--	----------*P*-value----------	--	
Acetochlor rate	0.0002†	<0.00001	<0.00001	0.0005
Fenclorim	0.30529	0.43304	0.54195	<0.00001
Acetochlor rate*fenclorim	0.88685	0.94753	0.87391	0.00713

† **Values less than 0.05 denote significance**.

Table 2. Visible injury to 'Diamond' rice plants 28 days after treatment in a field study at the University of Arkansas System Division of Agriculture's Northeast Research and Extension Center in Keiser, Arkansas.

Acetochlor rate	Fenclorim	Injury	
(lb ai/ac)	(lb ai/1000 lb-seed)	--------------------%	----------------
1.12	0	9.3	c†
1.68	0	32.5	b
2.25	0	48.8	a
1.12	2.5	2.5	c
1.68	2.5	2.5	c
2.25	2.5	9.3	c

† Different letters in a column signify statistical significance between treatments using Tukey's honestly significant difference with an α = 0.05.

Table 3. Palmer amaranth, horse purslane, and broadleaf signalgrass control 28 days after treatment +/- 3 days in a field study at the University of Arkansas System Division of Agriculture's Northeast Research and Extension Center in Keiser, Arkansas.

	Weed control					
Acetochlor rate	Palmer amaranth		Horse purslane		Broadleaf signalgrass	
(lb ai/ac)	-------------------------------------		%		-------------------------------------	
1.12	64	b†	33	c	39	c
1.68	83	a	59	b	78	b
2.25	93	a	75	a	88	a

† Different letters in a column signify statistical significance between treatments using Tukey's honestly significant difference with an α = 0.05.

Manipulation of Drill Width Spacing and Nozzle Selection for Weed Control in Rice

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B.M. Davis,[2] and M.R. Sumner[2]

Abstract

Arkansas rice producers have noticed an increase of resilient barnyardgrass [*Echinochloa crus-galli* (L.) P. Beauv.] becoming increasingly difficult to control. Cultural methods of drill width spacing manipulation and nozzle selection aid in controlling this hardy weed. The objective of this study was to evaluate the influence of nozzle type and rice drill width spacing on spray coverage and weed control in rice. Experiments were conducted at the University of Arkansas at the Pine Bluff Small Farm Outreach Center near Lonoke, Arkansas and the University of Arkansas System Division of Agriculture's Pine Tree Research Station near Colt, Arkansas, in 2021. Each plot was drill-seeded with four drill width spacings: 5, 7.5, 10, and 15 inches. Two herbicide applications were made with commonly used rice herbicides with 5 types of nozzles: XR, AIXR, TTI, TTI60, and AITTJ60, of which, the TTI60 and AITTJ60 were dual-fan nozzles. Barnyardgrass density counts were assessed at the 3-leaf rice stage and prior to harvest. Water-sensitive cards were placed and sprayed at the preflood stage to assess the percent spray coverage of each nozzle type. Both experiments showed no differences between the interaction of drill width spacing and nozzle types for any response variables. At the Lonoke location, barnyardgrass density was greater at 15-in. spacing than the 5-, 7.5-, and 10-in. spacing at the 3-leaf rice stage. The smaller droplet-sized nozzles (XR, AITTJ60, AIXR) produced a greater percent spray coverage than the larger droplet-sized nozzles (TTI60 and TTI), but no increase in coverage was observed from dual-fan nozzles. This research provided insights on a more precise drill width spacing and nozzle type selection to be used in rice standard practices.

Introduction

Since 1973, Arkansas has led the nation in rice (*Oryza sativa* L.) production and produces approximately 48% of the rice grown in the United States (Hardke, 2021). Chemical control methods are becoming less effective because herbicide-resistant weeds are rapidly evolving and diversified weed management strategies must be incorporated to increase weed control like manipulating drill width spacing (Norsworthy et al., 2013). Previous research has shown that a narrower drill width spacing suppresses weed growth more than wider drill width spacing with 7.5-in. spacing being the most used by producers (Chauhan and Opeña, 2013; Hardke, 2021). Because of hardy pests and drift complications, pesticide applications must be optimized by using the most optimal nozzle type to produce the greatest spray coverage (Butts et al., 2018). Using several TeeJet nozzles, it was observed that smaller droplet-sized nozzles produced a greater percent coverage of herbicides than larger droplet-sized nozzles (Priess et al., 2021). The objective of this study was to evaluate the influence of nozzle type and rice drill width spacing on spray coverage and weed control in rice.

Procedures

Two field experiments were conducted at the University of Arkansas at Pine Bluff Small Farm Outreach Center near Lonoke, Arkansas in 2021 and the University of Arkansas System Division of Agriculture's Pine Tree Research Station near Colt, Arkansas, in 2021. The experiments were designed as a randomized complete block split-plot design (24 treatments) replicated 4 times with 4 nontreated controls for each drill width spacing. Each plot consisted of 4 drill width spacings: 5 in., 7.5 in., 10 in., and 15 in. Each plot was sprayed with 2 applications of herbicides applied by 5 types of nozzles: single-fan-XR 11002, AIXR 11002, and TTI 11002; dual-fan-TTI60 11002 and AITTJ60 11002 (TeeJet Technologies, Wheaton, Ill.). The rice planted was a FullPage hybrid (RT 7521 FP) at 12 seeds ft/row. Two herbicide applications were made by a CO_2-pressurized sprayer on an ATV 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) was sprayed through the five types of nozzles. At the postemergence application timing, cyhalofop (Clincher) at 0.27 lb ai/ac (15 fl oz/ac) and halosulfuron + thifensulfuron (Permit Plus) at 0.03 + 0.004 lb ai/ac (0.75 fl oz/ac), respectively, was sprayed using the same types of nozzles. These applications were made to observe the nozzles' spray coverage across different rice drill widths and assist with weed control to bring the rice to yield. Barnyardgrass density assessment (2- 5.4 ft^2 quadrants) was assessed at 3-leaf and preharvest rice stage of the experiment. Rough rice yield was collected at the maturity of the crop. One water-sensitive card was placed per plot at 6 in. above the soil at the top of the rice

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canopy at preflood to measure droplet size and spray coverage. Water-sensitive spray cards were analyzed using DepositScan from the USDA-ARS Application Technology Unit to determine each card's droplet size (Dv0.5). The Dv0.5 is the droplet diameter in which 50% of the spray volume is contained in droplets with a lesser diameter. All data were subjected to analysis of variance, and means were separated using Fisher's protected least significant difference ($\alpha = 0.05$) using JMP Pro 16.0.

Results and Discussion

During the experiments, no differences were observed between the interaction of drill width spacing and nozzle type for any response variables. The droplet size of each nozzle type in order from the smallest droplet size to the largest was (Table 1): XR (417 µm), AITTJ60 (494 µm), AIXR (647 µm), TTI60 (850 µm), and TTI (910 µm). The smaller droplet sizes of the XR, AITTJ60, and AIXR all showed a greater percent spray coverage than the larger droplet sizes of TTI60 and TTI (Fig. 1). This result was similar to previous research highlighting the benefit of nozzle selection based on spray droplet size for improved coverage (Priess et al., 2021). However, no benefit in spray coverage was observed from the dual-fan nozzles (AITTJ60 and TTI60) compared to the single-fan nozzles with similar droplet sizes. During the 3-leaf rice growth stage at Lonoke, barnyardgrass density was lower at the 5-in., 7.5-in., and 10-in. drill width spacings than at 15-in. (Fig. 2). This corroborates previous drill width spacing work indicating narrower widths can improve weed control (Chauhan and Opeña, 2013). However, it may be possible to widen our current standard drill width spacing from 7.5 to 10 in. with no penalty in weed control. No barnyardgrass density differences were seen for drill width spacings across the locations at the preharvest stage. No differences were observed during harvest for the rough rice yield data.

Practical Applications

Even though the different drill width spacings all showed similar yields, it was observed that a narrower drill width spacing (≤10 in.) should be the first choice in drill-seeding rice to achieve greater barnyardgrass control. Wider drill width spacings (such as 15 in.) could be possible agronomically but more efforts on weed control would be required to reduce the soil seedbank. The smaller droplet size producing nozzles (XR, AIXR, AITTJ60) created the greatest percent spray coverage than the larger droplet sized nozzle (TTI and TTI60), and no advantage of having a dual-fan compared to a single-fan was observed. Therefore, it is likely more economical to select a single-fan nozzle of those tested in this research, and proper nozzle selection for each application should be based more on spray droplet size. Although no weed control differences were observed in the experiments, increased coverage of the herbicide increases the likelihood of a successful application.

Acknowledgments

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Literature Cited

Butts T.R., W. Hoffmann, J. Luck, and G. Kruger. 2018. Droplet velocity from broadcast agricultural nozzles as influenced by pulse-width modulation. Pesticide Formulation and Delivery Systems 38:24-52.

Chauhan B.S. and J. Opeña. 2013. Implications of plant geometry and weed control options in designing a low-seeding seed-drill for dry-seeded rice systems. Field Crops Res 144: 225-231

Hardke J.T. (2021) Introduction. Pages 1-8 in Arkansas rice production handbook. University of Arkansas System Division of Agriculture Cooperative Extension Service.

Norsworthy, J.K., J.A. Bond, and R.C. Scott. 2013. Weed management practices and needs in Arkansas and Mississippi rice. Weed Technol. 27: 623-630.

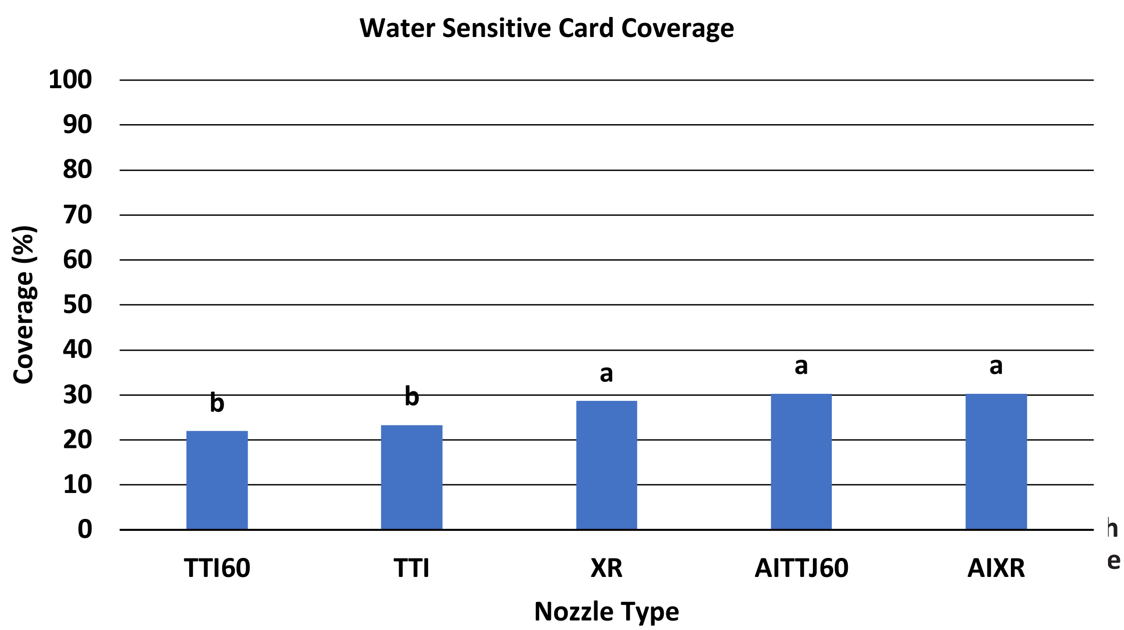
Priess G.L., J.K. Norsworthy, R.B. Farr, A. Mauromoustakos, T.R.Butts, and T.L. Roberts. 2021. Impact of auxin herbicides on Palmer amaranth (*Amaranthus palmeri*) groundcover. Weed Technol 35: 768-778.

Table 1. Droplet size of nozzle types used as determined from water-sensitive spray cards in two field experiments conducted at the University of Arkansas at Pine Bluff Small Farm Outreach Center near Lonoke, Arkansas in 2021 and the University of Arkansas System Division of Agriculture's Pine Tree Research Station near Colt, Arkansas, in 2021.†

Nozzle Type	Droplet size- ($D_{v0.5}$)‡
	(µm)
XR	417 a
AITTJ60	494 a
AIXR	647 a
TTI60	850 b
TTI	910 b

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

‡ $D_{v0.5}$ is the droplet diameter in which 50% of the spray volume is contained in droplets with a lesser diameter.



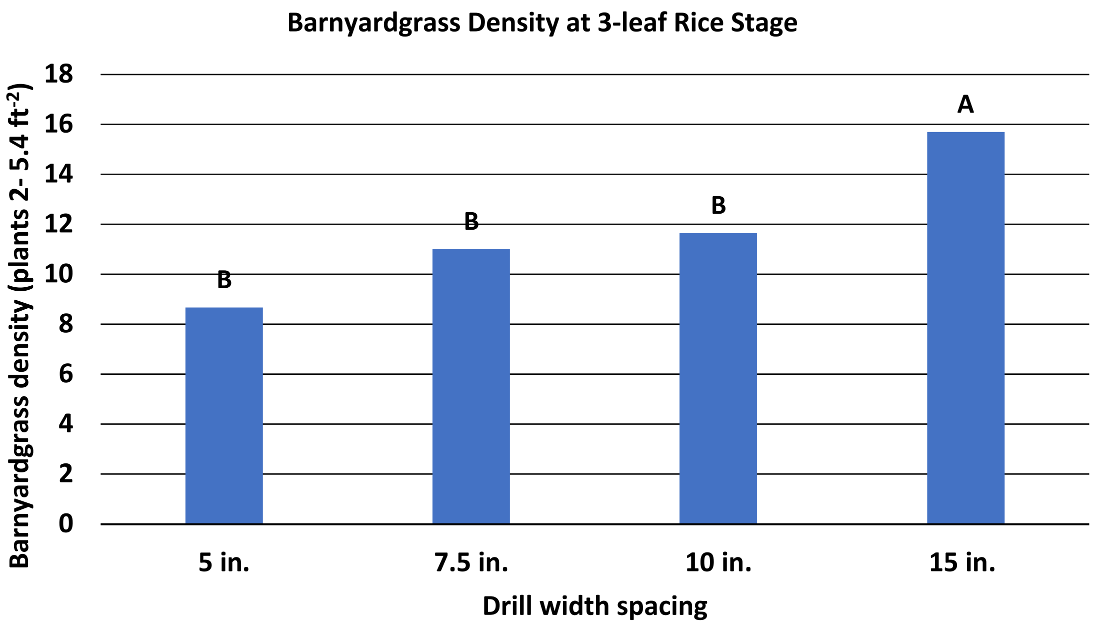


Fig. 2. Barnyardgrass density for each drill width spacing at 3-leaf rice stage at Lonoke, Arkansas. Treatments with the same letter are not different according to Fisher's protected least significant difference test at α = 0.05.

Grain Yield Response of Five New Rice Cultivars to Seeding Rate

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Abstract

Cultivar by seeding rate studies assist in developing production recommendations for new rice (*Oryza sativa*, L.) cultivars to determine necessary seeding rates that cover a range of Arkansas production/growing conditions. The 2021 study examined 5 rice cultivars, CLL16, CLL17, DG263L, Jewel, and Lynx. Seeding rates of 10, 20, 30, 40, and 50 seed/ft^2 were used for each cultivar. Current production recommendations were utilized at each location, and all seed received insecticide and fungicide seed treatments. Studies were seeded at 3 research station locations across eastern Arkansas. Differences were observed for stand density among seeding rates; however, there were few grain yield differences and no differences in milling yields. In 2021, even the lowest seeding rates produced stand densities at or near the recommended stand density range to produce optimal grain yields. The possibility of reduced stand density and grain yield should be noted if seed treatments for insecticides and fungicides are not used.

Introduction

Ideal rice (*Oryza sativa*, L.) stand density for pure-line cultivars in Arkansas is optimal at 10 to 20 plants/ft^2 (Hardke et al., 2018). In order to meet specific field conditions, the rice seeding rate is adjusted, but generally, 30 seed/ft^2 on silt loam soils and 36 seed/ft^2 on clay soils will obtain optimal stand density. Insecticide seed treatments, when properly applied, have shown to increase stand density by over 10% and increase grain yield by an average of 8 bu./ac (Taillon et al., 2015). In recent years, the use of insecticide seed treatments has increased, as approximately 80% of rice acres in Arkansas received an insecticide seed treatment in 2020 (Hardke, 2021). When planting rice without the use of an insecticide seed treatment, lower stand densities are increasingly likely.

Continued evaluation of seeding rates for new cultivars helps to determine an effective seeding rate and adapt to changing production practices, such as the use of insecticide and fungicide seed treatments. Determining an effective seeding rate is the foundation for additional production recommendations that can maximize the profit potential for rice growers as conditions change. The objective of this study was to determine the optimal seeding rate to maximize grain yield for 5 new rice cultivars in different growing conditions and environments common to rice production in Arkansas.

Procedures

In the 2021 cultivar by seeding rate study, trials were located on 3 University of Arkansas System Division of Agriculture research stations, including 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.; and the Northeast Research and Extension Center (NEREC) near Keiser, Ark. Both the RREC and the PTRS locations are on silt loam soils, while the NEREC location is on a silty clay soil. The RREC was seeded on 5 April, PTRS on 13 April, and NEREC on 19 April. Seed was treated with CruiserMaxx Rice seed treatment and AV-1011 bird repellent prior to planting. Seeding rates of 10, 20, 30, 40, and 50 seed/ft^2 were used for each cultivar. On well-prepared silt loam soils, the midpoint of 30 seed/ft^2 used is also the base recommendation corresponding with 65 to 80 lb seed/ac for most cultivars. Plot dimensions were 8 rows (7.5-in. spacing) by 17.5 ft in length. Recommended practices for maximum yield were followed. The experimental design for all trials was a randomized complete block design with 5 replications.

Stand density was measured by counting the number of emerged seedlings in 10 row ft and was determined approximately 3–4 weeks after planting. Preflood nitrogen (N) fertilization was 125, 145, and 160 lb N/ac for RREC, PTRS, and NEREC, respectively. After reaching maturity, the center 4 rows of each plot were harvested, with moisture content and weight of grain measured. A 12% moisture was used to adjust grain yields reported as bushels/acre (bu./ac). A bushel of rice weighs 45 lb. Data were analyzed using analysis of variance, PROC GLM, SAS v. 9.4 (SAS Institute, Inc., Cary, N.C.) with means separated using Fisher's least significant difference test ($P = 0.05$).

Results and Discussion

In 2021, the stand density of each entry was influenced by the seeding rate at each location. Stand density increased as the seeding rate increased for all cultivars at all locations (Table 1). Averaged across locations, the seeding rate did not affect grain yield for any cultivar.

At RREC, on a silt loam soil, stand densities within the recommended range of 10–20 plants/ft^2 were achieved with seed-

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ing rates of 20 seed/ft^2 for CLL16, CLL17, DG263L, and Jewel; and with seeding rates of 20 and 30 seed/ft^2 for Lynx (Table 2). The seeding rate did not influence the grain yield of any of the cultivars at RREC.

At PTRS, on a silt loam soil, stand densities within the recommended range of 10–20 plants/ft^2 were achieved with seeding rates of 20 and 30 seed/ft^2 for CLL16, CLL17, and Lynx; and with seeding rates of 20 seed/ft^2 for DG263L and Jewel (Table 3). Seeding rate only influenced grain yield for CLL16, where 40 seed/ft^2 produced higher grain yields compared to 10–30 seed/ft^2.

At NEREC, on a silty clay soil, stand densities within the recommended range of 10–20 plants/ft^2 were achieved with seeding rates of 20 seed/ft^2 for CLL16 and DG263L; with seeding rates of 20–30 seed/ft^2 for Jewel and Lynx; and with seeding rates of 20–40 seed/ft^2 for CLL17 (Table 4). The seeding rate did not influence the grain yield of any of the cultivars at NEREC.

Practical Applications

The findings from this study are based on results from silt loam and clay soils, and currently recommended seeding rate adjustments based on soil type and seeding date. Seeding rates lower than the current recommendation of 30 seed/ft^2 on silt loam soils and 36 seed/ft^2 on clay soils may produce a desirable grain yield if all conditions are favorable but risk insufficient stand densities that will be unable to maximize grain yield potential if unfavorable conditions occur within the growing season. Environmental conditions and field history should be taken into consideration when determining seeding rates outside of these study conditions.

Acknowledgments

The authors wish to thank all Arkansas rice growers for financial support through the Rice Check-off administered by the Arkansas Rice Research and Promotion Board, the support from the University of Arkansas System Division of Agriculture, Horizon Ag, and Nutrien Ag Solutions.

Literature Cited

Hardke, J.T. 2021. Trends in Arkansas Rice Production, 2020. *In:* J. Hardke, X. Sha, and N.R. Bateman (eds.). B.R. Wells Arkansas Rice Research Studies 2020. Arkansas Agricultural Experiment Station Research Series 676:11-18. Fayetteville.

Taillon, N.M., G.M. Lorenz, J. Black, W.A. Plummer, and H.M. Chaney. 2015. Insecticide seed treatments in rice: is there value to the grower? *In*: R.J. Norman and K.A.K. Moldenhauer (eds.). B.R. Wells Rice Research Studies 2015. Arkansas Agricultural Experiment Station Research Series 626:137-144. Fayetteville.

Table 1. Average stand density and grain yield of each cultivar averaged across all locations during 2021.†

Cultivar	CLL16		CLL17		DG263L		Jewel		Lynx	
	Stand	Yield	Stand	Yield	Stand	Yield	Stand	Yield	Stand	Yield
	plants/ft^2	bu./ac	plants/ft^2	bu./ac	plants/ft^2	bu./ac	plants/ft^2	bu./ac	plants/ft^2	bu./ac
10	7.9 e‡	183.0	7.1 d	163.8	8.9 e	219.6	9.2 e	158.4	7.4 e	196.3
20	14.0 d	188.3	12.2 c	163.5	15.8 d	224.6	14.1 d	161.3	13.5 d	202.9
30	21.0 c	187.7	17.5 b	173.7	22.5 c	220.8	21.4 c	165.7	18.6 c	197.4
40	24.9 b	190.2	23.4 a	170.7	27.1 b	223.6	26.6 b	166.5	23.7 b	204.9
50	30.6 a	189.2	24.5 a	172.6	29.6 a	219.4	32.7 a	164.0	29.1 a	202.4
P-value	<0.0001	NS§	<0.0001	NS	<0.0001	NS	<0.0001	NS	<0.0001	NS

† Data averaged across three locations: Rice Research and Extension Center (RREC) near Stuttgart, Ark., Pine Tree Research Station near Colt, Ark., and Northeast Research and Extension Center (NEREC) near Keiser, Ark.

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

§ NS = not significant.

Table 2. Influence of seeding rate on stand density and grain yield at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC) during 2021.[†]

Seeding Rate	Stand Density					Grain Yield				
	CLL16	CLL17	DG263L	Jewel	Lynx	CLL16	CLL17	DG263L	Jewel	Lynx
(seed/ft^2)	(plants/ft^2)					(bu./ac)				
10	9.1 e[‡]	8.1 d	9.8 e	9.8 d	8.0 e	174.5	169.9	220.5	163.2	188.1
20	15.7 d	14.3 c	16.5 d	16.4 c	13.2 d	173.3	157.6	219.3	154.3	189.9
30	22.7 c	19.2 b	21.9 c	23.7 b	19.2 c	171.2	159.8	223.0	159.1	181.7
40	27.9 b	26.3 a	26.5 b	26.4 b	22.9 b	172.3	167.0	220.0	159.1	192.1
50	35.9 a	29.2 a	31.3 a	34.4 a	28.2 a	167.4	173.5	212.8	154.3	187.3
P-value	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	NS[§]	NS	NS	NS	NS

[†] Research station field near Stuttgart, Arkansas, on silt loam soil.

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

[§] NS = not significant.

Table 3. Influence of seeding rate on stand density and grain yield at the University of Arkansas System Division of Agriculture's Pine Tree Research Station (PTRS) during 2021.[†]

Seeding Rate	Stand Density					Grain Yield				
	CLL16	CLL17	DG263L	Jewel	Lynx	CLL16	CLL17	DG263L	Jewel	Lynx
(seed/ft^2)	(plants/ft^2)					(bu./ac)				
10	7.0 e[‡]	7.0 d	8.2 c	8.7 e	6.5 e	149.5 c	152.2	187.9	182.0	174.9
20	13.7 d	11.2 c	13.8 b	13.3 d	12.7 d	156.3 bc	156.1	197.3	192.0	176.5
30	19.7 c	18.5 b	22.9 a	20.7 c	17.2 c	157.1 bc	161.0	192.6	192.1	180.9
40	25.3 b	23.8 a	26.3 a	29.1 b	24.3 b	167.5 a	152.8	199.4	193.4	180.5
50	29.7 a	23.4 a	26.0 a	34.1 a	27.3 a	163.4 ab	158.3	196.4	200.1	180.8
P-value	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0117	NS[§]	NS	NS	NS

[†] Research station field near Colt, Arkansas, on silt loam soil.

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

[§] NS = not significant.

Table 4. Influence of seeding rate on stand density and grain yield at the University of Arkansas System Division of Agriculture's Northeast Research and Extension Center (NEREC) during 2021.[†]

Seeding Rate	Stand Density					Grain Yield				
	CLL16	CLL17	DG263L	Jewel	Lynx	CLL16	CLL17	DG263L	Jewel	Lynx
(seed/ft^2)	(plants/ft^2)					(bu./ac)				
10	7.5 d[‡]	6.3 d	8.8 d	8.9 e	7.7 e	225.0	169.3	250.5	182.0	225.7
20	12.6 c	11.0 cd	17.2 c	12.6 d	14.6 d	235.3	176.6	257.1	192.0	242.4
30	20.5 b	14.9 bc	22.7 b	20.0 c	19.5 c	234.9	206.8	246.7	192.1	229.5
40	21.6 b	20.0 ab	28.5 a	24.2 b	24.0 b	230.8	192.3	251.4	193.4	242.1
50	26.1 a	21.0 a	31.3 a	29.6 a	31.8 a	236.6	185.8	248.9	200.1	239.2
P-value	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	NS[§]	NS	NS	NS	NS

[†] Research station field near Keiser, Arkansas, on silt loam soil.

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

[§] NS = not significant.

Arkansas Rice Performance Trials, 2021

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Abstract

The 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 2021 were in grower fields in Clay, Desha, Greene, Jackson, Lawrence, and Phillips counties and on research stations in Arkansas, Mississippi, Poinsett, and St. Francis counties. The average grain yield across all 11 trials was 206 bu./ac, with the highest average yielding location being Mississippi County at 227 bu./ac (Table 2). Cultivars that had the highest average grain yield across all locations include RT XP753, RT 7321 FP, RT 7401, RT 7301, RT 7521 FP, DG263L, Taurus, and Ozark. The average milling yield across all cultivars was 58/70 (%HR/%TR), with Jupiter, CLM04, Lynx, PVL02, and Taurus displaying the highest average milling yields.

Introduction

A goal of the University of Arkansas System Division of Agriculture is to provide complete production recommendations to growers for rice cultivars. This includes grain and milling yield potential, reactions to disease, fertilizer recommendations, and Degree-Day 50 (DD50) Rice Management Program thresholds. Other factors that can impact grain yield include seeding date, soil fertility, water quality and management, disease pressure, weather events, and cultural management practices.

Diseases that affect rice can play a major role in the profitability of any rice field within Arkansas. Ideal farming practices, host-plant resistance, and fungicide (if necessary, dependent on integrated pest management practices) provide the best fight against diseases that can lead to profit losses. Utilizing resistant cultivars along with quality cultural practices offers growers the opportunity for profit maximization while featuring lower disease control expenses by decreased use of costly fungicide applications.

For new cultivars, the majority of performance data is derived from research station locations. Problems that may not be evident in trials grown on experiment stations leave an incomplete dataset. This is due to a lack of environment variability that does not compare to the diversity of environments where Arkansas rice is grown. Information garnered from field research, combined with knowledge of a particular field's history, allows growers to make an informed decision when selecting a cultivar that offers the highest yield potential for any situation.

The design of the Arkansas Rice Performance Trial (ARPT) is to address many risks that new cultivars face across rice fields in Arkansas. New and commercial cultivar on-farm evaluations provide quality information on disease development, lodging, grain yield potential, and milling yield under varying environmental conditions and crop management practices. County agents, consultants, and producers also benefit from a hands-on educational opportunity.

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 the performance of rice cultivars under differing conditions from experiment stations.

Procedures

For the 2021 growing season, trial locations were in Arkansas, St. Francis, Mississippi, Poinsett (2), Clay, Desha, Greene, Jackson, Greene, and Phillips counties. A total of 21 cultivars were evaluated at each location. The conventional (non-herbicide-tolerant) entries observed were DG263L, Diamond, Jewel, Jupiter, Lynx, Ozark, ProGold1, ProGold2, RT XP753, RT 7301, RT 7401, Taurus, and

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Titan. Other lines included such as Clearfield, Provisia, and FullPage: CLL15, CLL16, CLL17, CLM04, PVL02, PVL03, RT 7321 FP, and RT 7521 FP, respectively.

Plots were 8 rows (7.5-in. spacing) wide and 18 ft in length with a randomized complete block design with 4 replications. Pure-line 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 24 March (Arkansas), 13 April (St. Francis), 19 April (Mississippi), 14 May (for both Poinsett trials), 5 April (Clay), 20 May (Desha), 12 April (Lawrence), 14 May (Jackson), 20 April (Greene), and 11 May (Phillips; Table 1). All plots were managed as conventional cultivars.

The ARPT locations had some cultural practice variations but were overall grown for the highest yield. Trials in commercials fields were supervised by the grower regarding the rest of the field. This included irrigation, fertilization, weed and insect control, and any fungicide application. Fungicide applications are included in disease ratings. Inspection of the plots for disease was rated periodically. Prior to harvest, percent lodging notes were taken. Harvested at maturity, the center 4 rows of each plot were cut while measuring moisture content and weight of grain. A subsample of each plot's grain was removed for milling purposes. Grain yields were adjusted to a 12% moisture and reported as bushels per acre (bu./ac). A rice bushel weighs 45 lb. 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 expression 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 2021 growing season had all 21 cultivars represented. Table 2 provides a summary of agronomic information related to each trial location. The grain yield average across all locations was 206 bu./ac (Table 2). The highest yielding cultivars across all locations were RT XP753, RT 7321 FP, RT 7401, RT 7301, and RT 7521 FP. The cultivars DG263L, Taurus, and Ozark were the highest-yielding non-hybrids. The medium-grains had the highest milling yields, led by Jupiter, CLM04, and Lynx, while PVL02, CLL17, and Jewel had the highest milling yields among the long-grains.

At Arkansas Co., the overall grain yield average was 222 bu./ac across all cultivars (Table 3). The highest yielding entries were RT XP753, RT 7301, Taurus, RT 7401, and Ozark. There was notable lodging with PVL02. The site had an average milling yield of 61/69 (%HR/%TR), with Lynx and CLM04 the highest medium-grains and PVL02 and PVL03 the highest long-grains.

The St. Francis Co. location had an average grain yield of 179 bu./ac, which was the lowest yield for any trial in 2021 (Table 4). The highest yielding entries were RT 7401, RT XP753, RT 7301, RT 7321 FP, and DG263L. The St. Francis Co. location had an average milling yield of 56/68 (%HR/%TR). The highest milling yield entries were PVL02, Jupiter, and CLL17.

The trial at Mississippi Co. had an average grain yield of 227 bu./ac (Table 5), which was the highest yield of any location in 2021. The highest grain yielding cultivars were RT 7401, RT XP753, RT 7321 FP, DG263L, and RT 7301. This location had the highest average milling yield at 64/71 (%HR/%TR). The highest milling entries were Taurus, Lynx, Jupiter, and CLM04, while PVL02 was highest for long-grains.

The first trial at Poinsett Co. had an average grain yield of 194 bu./ac (Table 6). Entries with the highest grain yields were RT XP753, RT 7521 FP, RT 7401, RT 7301, and RT 7321 FP. Taurus and DG263L were the highest yielding non-hybrids. The average milling yield of this trial was 63/70 (%HR/%TR). Entries that provided the highest milling yield included Lynx, Jewel, ProGold1, ProGold2, and Jupiter.

The second trial at Poinsett Co. had a grain yield average across all cultivars of 225 bu./ac (Table 7). The cultivars with the highest grain yields were RT 7321 FP, RT 7401, RT XP753, RT 7521 FP, and RT 7301. Taurus and Ozark were the highest yielding non-hybrids. Notable lodging occurred in PVL02, Lynx, CLL17, and CLM04. The average milling yield for this location was 64/71 (%HR/%TR). Cultivars with the highest milling results were Jupiter, Titan, Taurus, and CLM04.

The Clay Co. location was an on-farm trial with a grain yield average of 216 bu./ac (Table 8). The highest yielding entries were RT 7321 FP, RT 7521 FP, DG263L, RT 7301, and RT XP753. Lynx and RT 7521 FP had notable lodging. This location had the lowest total average milling yield of 46/69 (%HR/%TR). Cultivars with the highest milling yields included Jupiter, PVL02, Jewel, and CLM04.

The on-farm location in Desha Co. yielded an average of 191 bu./ac (Table 9). Entries with the highest grain yields were RT 7321 FP, RT 7301, RT XP753, Ozark, and Taurus. Entries with notable lodging included PVL02, CLL17, Lynx, Jupiter, Taurus, and CLM04. This location had an average milling yield of 62/70 (%HR/%TR). The highest milling yielding entries were Jupiter, Lynx, Titan, Taurus, and CLM04, while ProGold2 was the highest for long grains.

Lawrence Co. was an on-farm location with an average grain yield of 218 bu./ac (Table 10). The entries with the highest grain yields were RT XP753, RT 7321 FP, RT 7301, DG263L, Taurus, and RT 7521 FP. Cultivars RT 7521 FP, CLM04, and RT 7401 had notable lodging. The milling yield average for this location was 48/70 (%HR/%TR). Cultivars with the highest milling yields included Jupiter, PVL02, and CLM04.

The Jackson Co. on-farm location produced grain yields of 218 bu./ac (Table 11). Cultivars with the highest yields at this location were RT XP753, RT 7321 FP, RT 7521 FP, RT 7401, and RT 7301. Taurus and DG263L were the highest yielding non-hybrids. Entries with notable lodging included PVL02, RT 7521 FP, and RT 7401. The average milling yield was 59/71 (%HR/%TR) for this location. The highest milling yields were from Taurus, CLM04, Lynx, and Jupiter.

The on-farm location in Greene Co. had an average grain yield of 197 bu./ac (Table 12). The highest yielding entries were RT 7401, DG263L, RT 7521 FP, RT XP753, RT 7301, and RT 7321 FP. There was no lodging at harvest. Greene Co. had a milling yield of 52/70 (%HR/%TR). The highest milling cultivars were CLM04, Jupiter, Lynx, and PVL02.

The Phillips Co. on-farm location produced an average grain yield of 183 bu./ac (Table 13). Entries that yielded the highest

Table 2. Results of the Arkansas Performance Rice Trials (ARPT) at 11 Locations during 2021.

Cultivar	Grain Type[a]	Lodging[b]	Milling Yield[c]	Grain Yield by Location and Planting Date											
				ARK[d]	STF	MIS	POI1	POI2	CLA	DES	LAW	JAC	GRE	PHI	MEAN
		%	%HR/%TR	-----	-----	-----	-----	-----	bu./ac	-----	-----	-----	-----	-----	-----
Diamond	L	0	57/70	209	167	225	190	230	199	193	229	212	205	160	202
Jewel	L	0	60/70	202	155	216	163	214	208	176	197	197	177	151	187
ProGold1	L	0	57/70	216	159	224	187	229	182	203	218	214	202	166	200
ProGold2	L	0	55/70	203	158	202	185	224	178	190	211	192	186	149	189
Ozark	L	1	57/70	242	190	231	185	235	203	214	218	217	202	197	212
DG263L	L	2	56/68	232	200	250	209	224	238	210	240	225	233	196	223
PVL02	L	24	62/71	153	146	197	150	157	196	95	184	158	157	157	159
PVL03	L	0	58/71	216	152	211	147	211	200	175	195	186	151	185	185
CLL15	L	1	57/69	204	183	214	189	225	221	175	182	207	176	189	197
CLL16	L	0	55/69	212	177	225	185	215	210	186	217	212	201	170	201
CLL17	L	11	60/69	211	153	205	178	182	225	162	185	199	189	161	186
RT 7321 FP	L	0	52/70	233	209	253	230	273	247	244	246	259	215	230	240
RT 7521 FP	L	12	56/70	238	199	244	235	249	243	207	236	252	221	221	231
RT 7301	L	0	54/71	252	216	247	232	248	237	241	244	246	216	212	236
RT 7401	L	3	56/70	244	228	285	233	272	223	207	228	251	237	220	239
RT XP753	L	0	53/71	258	219	253	243	262	232	241	255	264	218	216	242
Lynx	M	15	63/70	231	170	221	183	186	225	155	219	227	179	177	197
Jupiter	M	3	65/69	210	159	204	180	222	214	190	218	213	188	165	197
Titan	M	1	59/70	228	173	211	193	211	226	193	216	209	207	170	203
Taurus	M	3	62/71	248	197	238	218	242	215	212	237	228	194	190	220
CLM04	M	10	64/70	218	140	212	160	205	220	139	201	212	180	165	187
MEAN		**4**	**58/70**	**222**	**178**	**227**	**194**	**225**	**216**	**191**	**218**	**218**	**197**	**183**	**206**
$LSD_{0.05}$[e]		NS	2/1	17	17	17	NS	NS	28	NS	21	16	18	17	7

[a] Grain length: L = long-grain; M = 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; STF = St. Francis Co., Pine Tree Research Station, Colt; MIS = Mississippi Co., Northeast Research and Extension Center, Keiser; POI1/POI2 = Poinsett Co., Northeast Rice Research and Extension Center, Harrisburg; CLA = Clay Co., producer field near McDougal; DES = Desha Co., producer field near Dumas; LAW = Lawrence Co., producer field near Walnut Ridge; JAC = Jackson Co., producer field near Newport; GRE = Greene Co.; producer field near Paragould; PHI = Phillips Co., producer field near Marvell.

[e] LSD = least significant difference.

were RT 7321 FP, RT 7521 FP, RT 7401, RT XP753, and RT 7301. Ozark, DG263L, and Taurus were the highest yielding non-hybrids. The average milling yield at Phillips Co. was 62/69 (%HR/%TR). The cultivars with the highest milling were Titan, RT 7401, Taurus, CLM04, PVL02, RT 7521 FP, and Jupiter.

Practical Applications

Data from the 2021 Arkansas Rice Performance Trials are made available to growers to assist in cultivar selection for upcoming seasons. In addition, these trials provide supplemental data to the rice breeding and disease resistance programs.

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Table 1. Cultural Data Summary for the 2021 Arkansas Rice Performance Trials.

County	City	Soil Class	Planting Date	Emergence Date	Harvest Date
Arkansas	Stuttgart	Dewitt silt loam	3/24	4/12	8/31
St. Francis	Colt	Calhoun-Henry silt loam	4/13	4/29	9/15
Mississippi	Keiser	Sharkey silty clay	4/19	5/4	9/22
Poinsett1	Harrisburg	Calloway-Henry silt loam	5/14	5/20	10/7
Poinsett2	Harrisburg	Henry silt loam	5/14	5/20	10/6
Clay	McDougal	Crowley silt loam/ Jackport silty clay	4/5	4/25	9/13
Desha	Dumas	Perry clay	5/20	6/5	10/13
Lawrence	Walnut Ridge	Beulah sandy loam/Patterson fine sandy loam	4/12	4/30	9/14
Jackson	Newport	Dundee silt loam	5/14	5/26	9/28
Greene	Paragould	Jackport silty clay loam	4/20	5/6	9/10
Phillips	Marvell	Foley silt loam	5/11	5/25	9/16

Table 3. Results of Arkansas County Arkansas Rice Performance Trial (ARPT) during 2021 (planted 24 March; harvested 31 August).

Cultivar	Grain Length[a]	Lodging[b]	Moisture[c]	Grain Yield	Milling Yield[d]
		(%)	(%)	(bu./ac)	(%HR/%TR)
Diamond	L	0	18	209	58/68
Jewel	L	0	18	202	57/69
ProGold1	L	0	18	216	60/68
ProGold2	L	0	17	203	61/71
Ozark	L	0	17	242	57/69
DG263L	L	0	19	232	58/67
PLV02	L	68	17	153	64/71
PVL03	L	0	18	216	62/69
CLL15	L	0	17	204	62/68
CLL16	L	0	20	212	59/68
CLL17	L	0	17	211	61/69
RT 7321 FP	L	0	17	233	58/70
RT 7521 FP	L	0	17	238	59/70
RT 7301	L	0	17	252	61/71
RT 7401	L	0	17	244	59/69
RT XP753	L	0	16	258	59/70
Lynx	M	0	19	231	67/70
Jupiter	M	0	23	210	65/69
Titan	M	0	19	228	65/70
Taurus	M	0	18	248	64/71
CLM04	M	0	19	218	67/70
Mean	-	3	18	222	61/69
$LSD_{0.05}$[e]	-	10	2	17	2/1

[a] Grain length: L = long-grain; M = 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 2021 (planted 13 April; harvested 15 September).

Cultivar	Grain Length[a]	Lodging[b]	Moisture[c]	Grain Yield	Milling Yield[d]
		(%)	(%)	(bu./ac)	(%HR/%TR)
Diamond	L	0	17	167	58/68
Jewel	L	0	17	155	59/69
ProGold1	L	0	16	159	59/68
ProGold2	L	0	16	158	59/69
Ozark	L	0	15	190	56/68
DG263L	L	0	16	200	56/66
PLV02	L	0	14	146	62/70
PVL03	L	0	15	152	58/69
CLL15	L	0	15	183	55/67
CLL16	L	0	18	177	55/66
CLL17	L	0	15	153	60/68
RT 7321 FP	L	0	13	209	49/67
RT 7521 FP	L	0	14	199	55/66
RT 7301	L	0	14	216	49/68
RT 7401	L	0	14	228	52/68
RT XP753	L	0	13	219	49/68
Lynx	M	0	15	170	58/68
Jupiter	M	0	18	159	62/67
Titan	M	0	15	173	51/68
Taurus	M	0	13	197	59/69
CLM04	M	0	16	140	59/67
Mean	-	0	15	179	56/68
$LSD_{0.05}$[e]	-	--	1	17	4/2

[a] Grain length: L = long-grain; M = 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 2021 (planted 19 April; harvested 22 September).

Cultivar	Grain Length[a]	Lodging[b]	Moisture[c]	Grain Yield	Milling Yield[d]
		(%)	(%)	(bu./ac)	(%HR/%TR)
Diamond	L	0	18	225	63/72
Jewel	L	0	18	216	63/71
ProGold1	L	0	18	224	66/71
ProGold2	L	0	17	202	63/72
Ozark	L	0	17	231	62/71
DG263L	L	0	15	250	59/69
PLV02	L	0	15	197	67/72
PVL03	L	0	16	211	66/73
CLL15	L	0	17	214	66/71
CLL16	L	0	20	225	64/71
CLL17	L	0	16	205	65/70
RT 7321 FP	L	0	14	253	59/72
RT 7521 FP	L	0	15	244	63/72
RT 7301	L	0	15	247	63/72
RT 7401	L	0	14	285	63/72
RT XP753	L	0	14	253	60/72
Lynx	M	0	17	221	69/71
Jupiter	M	0	20	204	68/70
Titan	M	0	17	211	66/72
Taurus	M	0	16	238	69/72
CLM04	M	0	18	212	68/71
Mean	-	0	17	227	64/71
$LSD_{0.05}$[e]	-	--	2	17	3/1

[a] Grain length: L = long-grain; M = 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 Poinsett1 County Arkansas Rice Performance Trial (ARPT) during 2021 (planted 14 May; harvested 7 October).

Cultivar	Grain Length[a]	Lodging[b]	Moisture[c]	Grain Yield	Milling Yield[d]
		(%)	(%)	(bu./ac)	(%HR/%TR)
Diamond	L	0	19	190	63/71
Jewel	L	0	18	163	65/71
ProGold1	L	0	18	187	65/71
ProGold2	L	0	17	185	65/71
Ozark	L	10	17	185	64/71
DG263L	L	0	18	209	61/68
PLV02	L	0	16	150	62/70
PVL03	L	0	17	147	64/71
CLL15	L	0	20	189	63/69
CLL16	L	0	21	185	63/70
CLL17	L	3	18	178	62/69
RT 7321 FP	L	0	16	230	59/70
RT 7521 FP	L	0	17	235	61/70
RT 7301	L	0	16	232	60/70
RT 7401	L	0	18	233	64/71
RT XP753	L	0	16	243	62/71
Lynx	M	0	18	183	67/71
Jupiter	M	0	19	180	65/69
Titan	M	0	19	193	64/70
Taurus	M	0	17	218	63/70
CLM04	M	0	18	160	65/70
Mean	-	1	18	194	63/70
$LSD_{0.05}$[e]	-	8	1	NS[f]	3/2

[a] Grain length: L = long-grain; M = 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.
[f] NS = not significant.

Table 7. Results of Poinsett2 County Arkansas Rice Performance Trial (ARPT) during 2021 (planted 14 May; harvested 6 October).

Cultivar	Grain Length[a]	Lodging[b]	Moisture[c]	Grain Yield	Milling Yield[d]
		(%)	(%)	(bu./ac)	(%HR/%TR)
Diamond	L	0	19	230	63/71
Jewel	L	0	18	214	65/71
ProGold1	L	0	18	229	65/71
ProGold2	L	0	18	224	65/71
Ozark	L	0	17	235	63/71
DG263L	L	0	18	224	61/69
PLV02	L	71	17	157	63/71
PVL03	L	0	17	211	65/71
CLL15	L	0	18	225	65/70
CLL16	L	0	21	215	65/71
CLL17	L	28	17	182	62/69
RT 7321 FP	L	0	16	273	61/72
RT 7521 FP	L	10	16	249	62/71
RT 7301	L	0	16	248	63/72
RT 7401	L	0	16	272	62/71
RT XP753	L	0	16	262	64/72
Lynx	M	49	21	186	66/72
Jupiter	M	0	20	222	67/70
Titan	M	0	18	211	66/70
Taurus	M	0	18	242	66/71
CLM04	M	25	19	205	66/70
Mean	-	9	18	225	64/71
$LSD_{0.05}$[e]	-	20	2	NS[f]	2/1

[a] Grain length: L = long-grain; M = 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.
[f] NS = =not significant.

Table 8. Results of Clay County Arkansas Rice Performance Trial (ARPT) during 2021 (planted 5 April; harvested 13 September).

Cultivar	Grain Length[a]	Lodging[b]	Moisture[c]	Grain Yield	Milling Yield[d]
		(%)	(%)	(bu./ac)	(%HR/%TR)
Diamond	L	0	11	199	46/69
Jewel	L	0	12	208	57/71
ProGold1	L	0	11	182	40/69
ProGold2	L	0	11	178	33/69
Ozark	L	0	10	203	46/69
DG263L	L	0	11	238	49/67
PLV02	L	0	12	196	58/71
PVL03	L	0	11	200	46/71
CLL15	L	0	12	221	44/69
CLL16	L	0	12	210	38/68
CLL17	L	0	12	225	49/69
RT 7321 FP	L	0	11	247	43/69
RT 7521 FP	L	28	11	243	40/69
RT 7301	L	0	10	237	37/70
RT 7401	L	5	10	223	40/69
RT XP753	L	0	10	232	32/70
Lynx	M	15	13	225	52/69
Jupiter	M	0	17	214	60/68
Titan	M	0	13	226	48/70
Taurus	M	0	12	215	50/71
CLM04	M	0	13	220	57/69
Mean	-	2	12	216	46/69
$LSD_{0.05}$[e]	-	12	1	28	12/1

[a] Grain length: L = long-grain; M = 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 Desha County Arkansas Rice Performance Trial (ARPT) during 2021 (planted 20 May; harvested 13 October).

Cultivar	Grain Length[a]	Lodging[b]	Moisture[c]	Grain Yield	Milling Yield[d]
		(%)	(%)	(bu./ac)	(%HR/%TR)
Diamond	L	0	17	193	62/69
Jewel	L	0	16	176	62/69
ProGold1	L	0	17	203	61/69
ProGold2	L	0	16	190	64/71
Ozark	L	0	16	214	61/70
DG263L	L	13	16	210	60/68
PLV02	L	99	21	95	63/70
PVL03	L	0	15	175	62/69
CLL15	L	8	15	175	61/67
CLL16	L	0	18	186	58/67
CLL17	L	93	19	162	62/68
RT 7321 FP	L	0	14	244	60/70
RT 7521 FP	L	10	17	207	63/70
RT 7301	L	0	14	241	62/72
RT 7401	L	0	16	207	62/70
RT XP753	L	0	14	241	62/71
Lynx	M	95	20	155	65/71
Jupiter	M	28	19	190	68/71
Titan	M	15	16	193	65/70
Taurus	M	30	16	212	65/70
CLM04	M	67	18	139	65/69
Mean	-	22	17	191	62/70
$LSD_{0.05}$[e]	-	31	2	NS[f]	2/1

[a] Grain length: L = long-grain; M = 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.
[f] NS = not significant.

Table 10. Results of Lawrence County Arkansas Rice Performance Trial (ARPT) during 2021 (planted 12 April; harvested 14 September).

Cultivar	Grain Length[a]	Lodging[b]	Moisture[c]	Grain Yield	Milling Yield[d]
		(%)	(%)	(bu./ac)	(%HR/%TR)
Diamond	L	0	13	229	52/71
Jewel	L	0	14	197	55/71
ProGold1	L	0	13	218	48/70
ProGold2	L	0	14	211	39/71
Ozark	L	0	13	218	48/70
DG263L	L	10	12	240	49/67
PLV02	L	0	12	184	57/72
PVL03	L	0	13	195	46/71
CLL15	L	0	11	182	44/64
CLL16	L	0	14	217	44/69
CLL17	L	0	13	185	55/69
RT 7321 FP	L	0	12	246	35/71
RT 7521 FP	L	54	12	236	43/70
RT 7301	L	5	12	244	38/71
RT 7401	L	15	11	228	42/70
RT XP753	L	5	13	255	43/71
Lynx	M	3	15	219	55/72
Jupiter	M	3	16	218	62/70
Titan	M	0	15	216	43/70
Taurus	M	5	14	237	56/71
CLM04	M	20	14	201	56/71
Mean	-	6	13	218	48/70
$LSD_{0.05}$[e]	-	22	2	21	8/3

[a] Grain length: L = long-grain; M = 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 Jackson County Arkansas Rice Performance Trial (ARPT) during 2021 (planted 14 May; harvested 28 September).

Cultivar	Grain Length[a]	Lodging[b]	Moisture[c]	Grain Yield	Milling Yield[d]
		(%)	(%)	(bu./ac)	(%HR/%TR)
Diamond	L	0	14	212	56/71
Jewel	L	0	15	197	62/72
ProGold1	L	0	14	214	58/71
ProGold2	L	0	15	192	53/71
Ozark	L	0	14	217	57/71
DG263L	L	4	14	225	58/69
PLV02	L	31	13	158	62/73
PVL03	L	0	14	186	58/71
CLL15	L	0	14	207	58/71
CLL16	L	0	16	212	57/71
CLL17	L	0	15	199	64/70
RT 7321 FP	L	0	13	259	51/71
RT 7521 FP	L	28	13	252	56/71
RT 7301	L	0	14	246	55/72
RT 7401	L	10	14	251	57/71
RT XP753	L	0	14	264	54/72
Lynx	M	0	16	227	66/72
Jupiter	M	0	18	213	65/70
Titan	M	0	16	209	60/71
Taurus	M	0	16	228	67/72
CLM04	M	0	18	212	67/72
Mean	-	3	15	218	59/71
$LSD_{0.05}$[e]	-	15	1	16	5/1

[a] Grain length: L = long-grain; M = 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 Greene County Arkansas Rice Performance Trial (ARPT) during 2021 (planted 20 April; harvested 9 October).

Cultivar	Grain Length[a]	Lodging[b]	Moisture[c]	Grain Yield	Milling Yield[d]
		(%)	(%)	(bu./ac)	(%HR/%TR)
Diamond	L	0	14	205	48/71
Jewel	L	0	14	177	58/71
ProGold1	L	0	13	202	44/70
ProGold2	L	0	14	186	39/70
Ozark	L	0	14	202	52/70
DG263L	L	0	13	233	52/68
PLV02	L	0	12	157	62/73
PVL03	L	0	13	151	46/71
CLL15	L	0	15	176	49/70
CLL16	L	0	16	201	47/70
CLL17	L	0	14	189	58/69
RT 7321 FP	L	0	12	215	38/70
RT 7521 FP	L	0	13	221	51/70
RT 7301	L	0	13	216	43/71
RT 7401	L	0	14	237	49/71
RT XP753	L	0	13	218	40/71
Lynx	M	0	18	179	65/70
Jupiter	M	0	22	188	66/69
Titan	M	0	17	207	57/71
Taurus	M	0	16	194	60/71
CLM04	M	0	19	180	67/71
Mean	-	0	15	197	52/70
$LSD_{0.05}$[e]	-	--	1	18	4/1

[a] Grain length: L = long-grain; M = 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 13. Results of Phillips County Arkansas Rice Performance Trial (ARPT) during 2021 (planted 11 May; harvested 16 September).

Cultivar	Grain Length[a]	Lodging[b]	Moisture[c]	Grain Yield	Milling Yield[d]
		(%)	(%)	(bu./ac)	(%HR/%TR)
Diamond	L	0	24	160	59/67
Jewel	L	0	23	151	61/69
ProGold1	L	0	23	166	63/70
ProGold2	L	0	24	149	63/69
Ozark	L	0	20	197	59/68
DG263L	L	0	20	196	58/67
PLV02	L	0	19	157	64/70
PVL03	L	0	22	185	62/69
CLL15	L	0	22	189	61/68
CLL16	L	0	26	170	59/68
CLL17	L	0	20	161	60/67
RT 7321 FP	L	0	17	230	59/70
RT 7521 FP	L	0	20	221	64/70
RT 7301	L	0	19	212	63/70
RT 7401	L	0	19	220	65/71
RT XP753	L	0	18	216	62/71
Lynx	M	0	23	177	63/68
Jupiter	M	0	25	165	64/68
Titan	M	0	22	170	66/70
Taurus	M	0	20	190	65/70
CLM04	M	0	23	165	65/69
Mean	-	0	21	183	62/69
$LSD_{0.05}$[e]	-	--	2	17	3/2

[a] Grain length: L = long-grain; M = 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 Twelve New Rice Cultivars to Nitrogen Fertilization

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Abstract

The purpose of the cultivar by nitrogen (N) studies is the observation and analysis of the response of new rice (*Oryza sativa* L.) cultivars to N fertilization in order to determine the optimal N fertilizer rates across an array of soils and environments in which rice is grown in Arkansas. Twelve cultivars were studied in 2021 and included: ARoma17, CLL16, CLL17, CLM04, DG263L, DGL274, Diamond, Jewel, Lynx, ProGold1, ProGold2, and PVL03 at 3 University of Arkansas System Division of Agriculture locations: the Northeast Research and Extension Center (NEREC), 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 most cultivars studied at the 3 locations in 2021, with lodging ranging from mild to none, with a few plots severely damaged at the PTRS location. The 2021 season was the first year the cultivars DGL274 and PVL03 were included, and the second year for DGL263L, ProGold1, and ProGold2; therefore, there is insufficient data to make an 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. Multiple years of results for ARoma17, Diamond, CLL16, CLM04, Jewel, and Lynx provide evidence that these cultivars should have good yields with minimal to no lodging if 150 pounds (lb) of N/ac is applied in a two-way split of 105 lb N/ac at the preflood timing followed by 45 lb N/ac at midseason when grown on silt loam soils and 180 lb N/ac in a two-way split of 135 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 by nitrogen (N) fertilizer rate trials are to record and analyze the grain yield performance of new rice (*Oryza sativa* L.) cultivars over a range of fertilizer rates on a representative clay and 2 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 12 cultivars were included in 2021 at 3 locations.

Procedures

The cultivar by N fertilizer rate studies were conducted at the following University of Arkansas System Division of Agriculture research locations: the Northeast Research and Extension Center (NEREC) near Keiser, Ark., on a Sharkey Clay (Vertic Haplaquepts) 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 cultivars studied were ARoma17, CLL16, CLL17, CLM04, DG263L, DGL274, Diamond, Jewel, Lynx, ProGold1, ProGold2, and PVL03. 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 8 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 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 of N/ac rate. Pertinent agronomic dates and practices for each location are reported in Table 1. The permanent flood was established within 24–48 hours of the preflood N application and maintained until maturity of the rice crop. At maturity, the flood was released. 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%

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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 by N studies in response to the rising cost of N fertilizer and the preference for medium to short stature, semi-dwarf, and stiff straw plant type currently grown. These cultivars typically reach maximal yield potential when less N is applied in a single preflood application in comparison with the traditional two-way split application. Typically cultivars receiving a single preflood application require 20 to 30 lb N/ac less than when N is applied in a two-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 two-way application, then 120 to 130 lb N/ac should maximize yield potential using a single preflood application as long as 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 2021 cultivar by N rate trials were fair to good for most of the 12 cultivars included. Maximal yields ranged from 154 to 237 bu./ac for the NEREC location, 127 to 218 bu./ac at the PTRS location, and 130–218 bu./ac for the RREC location. There were minimal lodging scores reported, with a few plots severely damaged by wildlife at the PTRS location. In 2020, planting dates in late April at RREC yielded higher compared to earlier or later-planted rice, while rice planted in early May yielded best at PTRS compared to other planting dates (Clayton et al., 2021). This may explain the reduction in yield for the PTRS location compared to the information gathered in 2020 (Castaneda-Gonzalez, 2021), a difference ranging from 23 to 30 bu./ac. Differences in yield for NEREC ranged from 2 to 9 bu./ac and from 24 to 55 bu./ac at RREC in comparison to last year's data. Torrential rains and cloudiness early in the season may have had an influence on these yield reductions. Yield results and response to N of Diamond (check cultivar) in this year's cultivar by N trial support data from previous years and indicate that the overall results of the trial align with previous research. Hence the results validate current recommendations for the soil types favorable for rice culture.

The cultivar ARoma 17 achieved a maximal yield of 192 bu./ac at the NEREC location, followed by 134 bu./ac at RREC and 127 bu./ac at the PTRS when N rates of 210, 180, and 120 lb N/ac were applied, respectively (Table 2). The data suggests that this cultivar's yields tend to plateau between 150–180 lb N/ac for clay soils and 120–150 lb N/ac for silt loam soils. The lowest preflood N rate that produced a statistically similar yield to the maximal yield for a given location was identified as 120 lb N/ac for the clay soil and 90 lb N/ac in a single preflood application for the 2 silt loam soils, the N rate being lower than the 2 previous years where the least N fertilizer to obtain yields not statistically different to the maximal yield was 150 lb N/ac and 120 lb N/ac for clay and silt loam soils, respectively (Castaneda-Gonzalez et al., 2020; 2021). The response of this cultivar to N fertilization appears to be linear for PTRS, but the response was quadratic for NEREC and RREC, where N rates of above 120 lb N/ac resulted in decreasing yields. These results are not completely in agreement with the results of the last 2 years, where the response was linear. These results, in combination with the previous years of data, suggest that this variety will yield in the range of 180–190 bu./ac with minimal to no lodging when a single preflood application of 120 lb N/ac for silt loam soils and 150 lb N/ac for clay soils is provided, or its equivalent, 150 lb N/ac and 180 lb N/ac when a split application is preferred.

The rice cultivar CLL16 showed a significant reduction of yield in comparison with the previous 2 years on silt loam soils and similar performance on clay soil. On silt loam soils, it has shown the potential to produce over 200 bu./ac (Castaneda-Gonzalez et al., 2020, Castaneda-Gonzalez et al., 2021). In 2021, a peak yield of 183 bu./ac was recorded at the RREC and the PTRS when 120 lb N/ac was applied (Table 3). The yields at NEREC were 4 to 5 bu./ac lower than those reported for PTRS and RREC, with a peak yield of 179 bu./ac when 120 lb N/ac was applied. The lowest yield-maximizing N rate was 90, 120, and 60 lb N/ac for the NEREC, PTRS, and RREC locations, respectively, differing from the previous 2 years of study (Castaneda-Gonzalez et al., 2020; 2021). The yield response for this cultivar is quadratic, meaning that once the maximal yield is achieved with a particular N treatment, any additional N has no significant effect or the response is actually negative, i.e., yield decreases. This cultivar displays a stable trend of grain yield production with minimal to no lodging reported except for the highest N rate and under added environmental stress, and the results are generally consistent with those of previous years. These results, combined with those from previous years, suggest N rates of 120 lb N/acre for silt loam soils and 150 lb N/acre for clay soils in a SPF, or 150 lb N/ac for silt loam soils and 180 lb N/ac for clay soils applied in a split application are required to maximize grain yield.

For the cultivar CLL17, peak yields of 170, 172, and 173 bu./ac were realized at the 150, 150, and 90 lb N/ac preflood N rates (Table 4) for NEREC, PTRS, and RREC, respectively. The response to N fertilization appeared to be quadratic for all locations and in agreement with the previous year's results. For all locations, additional fertilizer beyond 150 lb N/ac resulted in yields not being different or resulted in a reduction of yields at the highest N rates. Yields were inconsistent with results from the previous year, which indicated that CLL17 should be able to sustain yields of 180 to 200 bu./ac across different environments and soils with minimum to no lodging. Additional research will be needed in order to refine N requirements for this cultivar.

Grain yield response for cultivar CLM04 to N fertilization appeared to be quadratic for all locations reaching peak yield at 159 bu./ac (150 lb N/ac), 182 bu./ac (150 lb N/ac), and 190 bu./ac (150 lb N/ac) for NEREC, PTRS, and RREC, respectively (Table 5). The lowest yield maximizing N rates were 90 lb/ac for NEREC and 150 lb N/ac for PTRS and RREC. Yields were stable for this cultivar across the top 3 (NEREC) or top 2 (PTRS and RREC) preflood N rates. This is the third year that CLM04 has been included in the cultivar by N trials, and the results are similar to the previous 2 years. However, due to the stable yield at and above preflood N rates of 120 lb N/ac at the PTRS and RREC locations, it appears that this cultivar will most likely perform best when 120 lb N/ac on silt loam soils and 150 lb N/ac on clay soils in a SPF or 150 lb N/ac on a silt loam soil and 180 lb N/ac in a split application is provided.

The overall yields of the cultivar DG263L, included for the second time in the cultivar by N studies, were among the highest of all cultivars tested in the 2021 trials (Table 6). The peak yields recorded for this cultivar were 239, 218, and 224 bu./ac at N rates of 210, 180, and 90 lb N/ac for the NEREC, PTRS, and RREC, respectively. The response to N rate was linear for NEREC and PTRS, and quadratic for RREC, where levels of N above 90 lb N/ac resulted in lower yields. The yields were stable across all soil types and most N rates with excellent standability. The 2021 results being mostly in agreement with data of the previous 2 years and yields above 200 bu./ac make this a very promising variety. The lowest yield-maximizing N rates were 90 lb N/ac for all locations. The overall response to N rates was linear, although any gains in yield above the aforementioned N rates were not statistically different.

The cultivar DGL274 was added in 2021 for the first time to the cultivar by N trials. It recorded a peak grain yield of 225 bu./ac (210 lb N/ac) at NEREC, 218 bu./ac (180 lb N/ac) at PTRS, and 224 bu./ac (120 lb N/ac) at RREC (Table 7). The response of DGL274 was linear except for RREC, where N rates exceeding 120 lb N/ac resulted in lower yields proportional to N rates. The lowest yield-maximizing N rates were 180 lb N/ac for the NEREC location, and 90 lb N/ac for the PTRS and RREC locations. Additional data needs to be collected for DGL274 to make an accurate assessment of this cultivar and its optimal N fertilization strategy.

The cultivar Diamond 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 by N studies. In 2021, maximal yields for Diamond were 218 bu./ac (150 lb N/ac), 197 bu./ac (180 lb N/ac) and 192 bu./ac (120 lb N/ac) for NEREC, PTRS, and RREC, respectively. The yield response to N rate was linear for PTRS, and quadratic for NEREC and RREC, with minimum N rates to achieve maximal yield not significantly different from the peak yield being 120 lb N/ac (200 bu./ac) at NEREC, 120 lb N/ac (176 bu./ac) at PTRS, and 90 lb N/ac (181 bu./ac) at RREC (Table 8). Diamond performance is similar across sites, N rates, and years. It is against this variety that the results gathered in 2021 must be compared to make assessments.

The 2021 season is the third year that Jewel is included in the cultivar by N test. Jewel maximal yields were 208 bu./ac (150 lb N/ac) at NEREC, 163 bu./ac (180 lb N/ac) at PTRS, and 173 bu./ac (120 lb N/ac) for RREC (Table 9). The yield response was quadratic for NEREC and RREC while linear for PTRS. This type of response that insofar has been observed in some of the varieties already discussed provides evidence of the validity of our test as well as the differences observed with previous studies underlining the effects on environmental stresses beyond the main treatments (cultivar and N rate). With caution, it is valid to state that Jewel should perform well when current N fertilizer rate recommendations for silt loam and clay soils, 150 and 180 lb N/ac, respectively, are made in a split application.

This is the third year for Lynx in the cultivar by N trial that produced maximal yields near or above 200 bu./ac at all three locations (Castaneda-Gonzalez et al., 2020; 2021). In 2021, the maximal yield of Lynx was achieved when 150 lb N/ac (226 bu./ac) was applied at NEREC, 180 lb N/ac (214 bu./ac), at PTRS, and 120 lb N/ac (193 bu./ac), at RREC (Table 10). These results indicate a linear relationship between fertilizer rate and yield for the PTRS location and a quadratic response for NEREC and RREC, reflecting results from the previous 2 years. The lowest yield-maximizing N rate was 150, 90, and 120 lb N/ac for the NEREC, PTRS, and RREC locations, respectively. Nitrogen rates above these levels resulted in higher yields that were numerically greater but not statistically different, or in lower yields at the higher rates as for the RREC and NEREC locations. Overall, Lynx offers good to excellent yields with good standability across environmental and soil conditions. Based on the results of 3 consecutive years of cultivar × N trials, there is enough evidence to suggest following the current N recommendations of 150 lb N/ac for silt loam soils and 180 lb N/ac applied for clay soils in a split application. It should be noted that this cultivar has displayed the potential for lodging when excessive N rates are applied, so caution should be used when selecting an appropriate N rate for a given field.

The 2021 growing season is the third year that the cultivar ProGold1 was included in the cultivar by N test. In this year's trials, ProGold1 was one more of the cultivars reaching yields of 200 or more bu./ac in at least one location, with yields approaching those of Diamond for the same year (Table 11). Peak yields of 218 (180 lb N/ac), 182 (180 lb N/ac), and 175 (90 lb N/ac) bu./ac were recorded for the NEREC, PTRS, and RREC, respectively. While yield seems to increase with N rate, at least for the PTRS location, rates above 150 lb N/ac for silt loam soils and 180 lb N/ac for clay soil resulted in a reduction in yields. A similar response was observed in the preceding 2 years, making the yield response of this variety to N rate linear for PTRS and quadratic for NEREC and RREC. The lowest N rates that produced a yield not statistically different from the peak yields were 120, 150, and 90 lb N/ac for NEREC, PTRS, and RREC, respectively. ProGold1 offers an excellent and stable yield potential with good standability in diverse environmental and soil conditions according to the results obtained in the three years of study and should be a good performer when 150 lb N/ac for silt loam soils and 180 lb N/ac for clay soils are provided in a split application.

The yield response to N fertilization of the cultivar ProGold2, in its second season of inclusion in the cultivar by N studies, was linear for the silt loam soils and quadratic for the clay soil. Recorded peak yields were 205 bu./ac (150 lb N/ac), 178 bu./ac (180 lb N/ac), and 185 bu./ac (180 lb N/ac) for NEREC, PTRS, and RREC locations, respectively (Table 12); although, the lowest yield maximizing N rates were found to be 90, 120, and 60 lb N/ac for NEREC, PTRS, and RREC, respectively. Any yield gains due to increased N rates above the aforementioned lowest yield maximizing rates were found to be not statistically different. More research will be necessary for the characterization of the yield response to N rates of ProGold2, as well as for making any attempt of making any recommendation in respect to fertilizer N needs.

The cultivar PVL03 was included in the cultivar by N trials for the first time. Yields for this cultivar ranged from moderate to fair at the 3 locations, with the overall highest yields reported at the NEREC location. Peak yields for PVL03 were 181 bu./ac (180 lb N/ac), 153 bu./ac (180 lb N/ac), and 195 bu./ac (150 lb N/ac) at the NEREC, PTRS, and RREC locations, respectively (Table 13), making the yield response to N fertilization rates quadratic for NEREC and RREC and linear for PTRS. The least N rates resulting in yields not statistically different from the peak yields were 90 lb N/ac for NEREC and for PTRS, and 120 lb N/ac for RREC. Additional data will be required to make N rate recommendations for PVL03.

Practical Applications

The cultivar by 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 as per lb of N applied when grown commercially in the Arkansas rice-growing region. Within the cultivar × 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 for multi-year testing. The 2021 growing season was a year of opportunity to test the sustainability of yields under unusual environmental conditions. The rice cultivars included in 2021 were: ARoma 17, CLL16, CLL17, CLM04, DG263L, DGL274, Diamond, Jewel, Lynx, ProGold1, ProGold2, and PVL03. Most cultivars included in the 2021 cultivar by N trial are in the second or third year of assessment, and results were confounded with the effects of weather phenomena and possible herbicide drift; therefore, more data collection is required in order to make the best possible recommendations on N fertilizer management.

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Literature Cited

Castaneda-Gonzalez, E., T.L. Roberts, J.T. Hardke, N.A. Slaton, K.A.K. Moldenhauer, X. Sha, D.L. Frizzell, M. W. Duren and T. D. Frizzell. 2020. Grain yield response of eleven new rice cultivars to nitrogen fertilization. *In*: K.A.K. Moldenhauer, B. Scott, and J. T. Hardke (eds.), B.R. Wells Arkansas Rice Research Studies 2019. University of Arkansas Agricultural Experiment Station Research Series 667:162-169.

Castaneda-Gonzalez, E., T.L. Clayton, T.L. Roberts, J.T. Hardke, K.A.K. Moldenhauer, X. Sha, D.L. Frizzell, T.D. Frizzell, L.R. Amos, and K.F. Hale. 2021. Grain Yield Response of Twelve New Rice Cultivars to Nitrogen Fertilization. *In:* J. T. Hardke, X. Sha, and N. Bateman (eds.), B.R. Wells Arkansas Rice Research Studies 2020. University of Arkansas Agricultural Experiment Station Research Series 676:181-191.

Clayton, T.L., J.T. Hardke, D.L. Frizzell, R.J. Norman, W.J. Plummer, K.F. Hale, T.D. Frizzell, A. Ablao, K.A.K. Moldenhauer, and X. Sha. 2020. 2019 Degree-Day 50 (DD50) Thermal Unit Threshold for New Rice Cultivars and Seeding Dates Studies. *In*: K.A.K. Moldenhauer, B. Scott, and J. Hardke (eds.), B. R. Wells Arkansas Rice Research Studies 2019. University of Arkansas Agricultural Experiment Station Research Series 667:182-190.

Norman, R.J., C.E. Wilson Jr., and N.A. Slaton. 2003. Soil Fertilization and Mineral Nutrition in U. S. Mechanized Rice Culture. *In*: C.W. Smith and R. H. Dilday (eds.). RICE. Origin, History, Technology, and Production. Wiley Series in Crop Science. C. Wayne Smith, Series Editor. John Wiley & Sons, Inc. Hoboken, New Jersey. USA. p. 331-411.

Roberts, T.L., N.A. Slaton, C. Wilson, Jr., and R.J. Norman. 2018. Soil Fertility. *In*: J.T. Hardke (Ed), Rice Production Handbook. University of Arkansas System Division of Agriculture Cooperative Extension Service, Little Rock, Ark. p. 69-102.

Table 1. Pertinent agronomic information for the University of Arkansas System Division of Agriculture's Northeast Research and Extension Center (NEREC), Pine Tree Research Station (PTRS), and the Rice Research and Extension Center (RREC) during 2021.

Practices	NEREC	PTRS	RREC
Planting Dates	19 April 2021	13 April 2021	5 April 2021
Herbicide Spray Dates and Spray Procedures	22 April 2021 1.3 pt Command + 43 oz Facet L + 0.75 oz Permit Plus Broadcast	13 April 2021 3.2 oz League + 24 oz Facet L + 8 oz Command. Broadcast	6 April 2021 4 oz League + 10 oz Command Broadcast
Flush Dates	----	----	21 April 2021
Emergence Dates	4 May 2021	29 April 2021	21 April 2021
Herbicide Spray Dates and Spray Procedures	17 June 2021 0.75 oz Permit Plus + 1% COC	7 May 2021 3 qt Propanil + 0.75 Permit Plus. Broadcast	27 May 2021 32 oz Facet L + 24 oz Ricestar Broadcast
Herbicide Spray Dates and Spray Procedures	----	5 June 2021 4 qt Propanil + 32 oz Prowl H_2O. Broadcast	15 June 2021 15 oz Clincher + 1 qt COC[†] Broadcast
Herbicide Spray Dates and Spray Procedures	----	17 June 2021 24 oz Ricestar + 20 oz Facet L Broadcast	13 July 2021 20 oz Clincher + 1 qt COC Broadcast
Preflood N Dates	16 June 2021	16 June 2021	14 June 2021
Flood Dates	18 June 2021	17 June 2021	16 June 2021
Insecticide Spray Dates and Spray Procedures	22 July 2021 2 oz Warrior II	None	None
Drain Dates	7 September 2021	8 September 2021	31 August 2021
Harvest Dates	29 September 2021	17 September 2021	9 September 2021

[†] COC = crop oil concentrate.

Table 2. Influence of nitrogen (N) fertilizer rate on the grain yield of ARoma 17 rice at the University of Arkansas System Division of Agriculture's Northeast Research and Extension Center (NEREC), Pine Tree Research Station (PTRS), and the Rice Research and Extension Center (RREC) during 2021.

	Grain Yield		
N Fertilizer Rate	**NEREC†**	**PTRS**	**RREC**
(lb N/ac)	---------------------------------------(bu./ac)---		
0	102 c‡	102 c	102 c
60	-----	-----	-----
90	143 b	143 b	143 b
120	167 a	167 a	167 a
150	177 a	177 a	177 a
180	184 a	184 a	184 a
210	192 a	192 a	192 a

† NEREC = Northeast Research and Extension Center, Keiser, 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 CLL16 rice at the University of Arkansas System Division of Agriculture's Northeast Research and Extension Center (NEREC), Pine Tree Research Station (PTRS), and the Rice Research and Extension Center (RREC) during 2021.

	Grain Yield		
N Fertilizer Rate	**NEREC†**	**PTRS**	**RREC**
(lb N/ac)	---------------------------------------(bu./ac)---		
0	87 b‡	99 d	138 c
60	----	149 c	179 a
90	171 a	170 b	182 a
120	179 a	183 a	183 a
150	176 a	181 ab	174 ab
180	177 a	190 a	159 b
210	127 ab	----	----

† NEREC = Northeast Research and Extension Center, Keiser, 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 CLL17 rice at the University of Arkansas System Division of Agriculture's Northeast Research and Extension Center (NEREC), Pine Tree Research Station (PTRS), and the Rice Research and Extension Center (RREC) during 2021.

	Grain Yield		
N Fertilizer Rate	NEREC†	PTRS	RREC
(lb N/ac)	---------------------------------------(bu./ac)---------------------------------------		
0	106 b‡	88 d	131 c
60	----	143 c	163 ab
90	170 a	151 b	173 a
120	163 a	163 a	167 ab
150	170 a	172 a	167 ab
180	165 a	171 a	157 b
210	162 a	----	----

† NEREC = Northeast Research and Extension Center, Keiser, 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 CLM04 rice at the University of Arkansas System Division of Agriculture's Northeast Research and Extension Center (NEREC), Pine Tree Research Station (PTRS), and the Rice Research and Extension Center (RREC) during 2021.

	Grain Yield		
N Fertilizer Rate	NEREC†	PTRS	RREC
(lb N/ac)	---------------------------------------(bu./ac)---------------------------------------		
0	85 b‡	84 e	127 d
60	----	132 d	163 c
90	137 a	156 c	175 bc
120	144 a	167 bc	182 ab
150	159 a	182 a	190 a
180	155 a	180 ab	187 ab
210	153 a	----	----

† NEREC = Northeast Research and Extension Center, Keiser, 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 DG263L rice at the University of Arkansas System Division of Agriculture's Northeast Research and Extension Center (NEREC), Pine Tree Research Station (PTRS), and the Rice Research and Extension Center (RREC) during 2021.

	Grain Yield		
N Fertilizer Rate	**NEREC**[†]	**PTRS**	**RREC**
(lb N/ac)		**(bu./ac)**	
0	142 b[‡]	126 c	157 d
60	----	184 b	202 c
90	226 a	202 a	224 a
120	237 a	214 a	220 ab
150	233 a	206 a	207 bc
180	221 a	218 a	206 bc
210	239 a		

[†] NEREC = Northeast Research and Extension Center, Keiser, 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 DGL274 rice at the University of Arkansas System Division of Agriculture's Northeast Research and Extension Center (NEREC), Pine Tree Research Station (PTRS), and the Rice Research and Extension Center (RREC) during 2021.

	Grain Yield		
N Fertilizer Rate	**NEREC**[†]	**PTRS**	**RREC**
(lb N/ac)		**(bu./ac)**	
0	87d[‡]	90 d	137 b
60	----	140 c	212 a
90	177 c	172 b	224 a
120	198 b	192 ab	224 a
150	209 ab	197 ab	218 a
180	209 ab	218 a	202 a
210	225 a	----	----

[†] NEREC = Northeast Research and Extension Center, Keiser, 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 Diamond rice at the University of Arkansas System Division of Agriculture's Northeast Research and Extension Center (NEREC), Pine Tree Research Station (PTRS), and the Rice Research and Extension Center (RREC) during 2021.

	Grain Yield		
N Fertilizer Rate	**NEREC**†	**PTRS**	**RREC**
(lb N/ac)	---------------------------------------(bu./ac)---------------------------------------		
0	91 c‡	93 c	129 c
60	----	158 b	170 b
90	168 b	165 b	181 ab
120	200 ab	176 ab	192 a
150	218 a	185 a	191 a
180	215 a	197 a	183 ab
210	208 ab	----	----

† NEREC = Northeast Research and Extension Center, Keiser, 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 Jewel rice at the University of Arkansas System Division of Agriculture's Northeast Research and Extension Center (NEREC), Pine Tree Research Station (PTRS), and the Rice Research and Extension Center (RREC) during 2021.

	Grain Yield		
N Fertilizer Rate	**NEREC**†	**PTRS**	**RREC**
(lb N/ac)	---------------------------------------(bu./ac)---------------------------------------		
0	117 c‡	59 c	109 c
60	----	130 b	141 b
90	176 b	143 ab	165 a
120	196 ab	145 ab	173 a
150	208 a	157 a	168 a
180	202 ab	163 a	169 a
210	197 ab	----	----

† NEREC = Northeast Research and Extension Center, Keiser, 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 10. Influence of nitrogen (N) fertilizer rate on the grain yield of Lynx rice at the University of Arkansas System Division of Agriculture's Northeast Research and Extension Center (NEREC), Pine Tree Research Station (PTRS), and the Rice Research and Extension Center (RREC) during 2021.

	Grain Yield		
N Fertilizer Rate	NEREC[†]	PTRS	RREC
(lb N/ac)	(bu./ac)		
0	104 c[‡]	119 d	134 c
60	----	173 c	180 b
90	192 b	200 ab	183 ab
120	193 b	189 bc	193 a
150	225 a	208 ab	187 ab
180	211 ab	214 a	192 a
210	210 ab	----	----

[†] NEREC = Northeast Research and Extension Center, Keiser, 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 11. Influence of nitrogen (N) fertilizer rate on the grain yield of rice line ProGold1 at the University of Arkansas System Division of Agriculture's Northeast Research and Extension Center (NEREC), Pine Tree Research Station (PTRS), and the Rice Research and Extension Center (RREC) during 2021.

	Grain Yield		
N Fertilizer Rate	NEREC[†]	PTRS	RREC
(lb N/ac)	(bu./ac)		
0	115 c[‡]	79 e	114 c
60	----	129 d	158 b
90	196 b	156 c	175 a
120	207 ab	163 bc	168 ab
150	216 a	174 ab	173 ab
180	217 a	182 a	167 ab
210	210 ab	----	----

[†] NEREC = Northeast Research and Extension Center, Keiser, 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 12. Influence of nitrogen (N) fertilizer rate on the grain yield of ProGold2 rice at the University of Arkansas System Division of Agriculture's Northeast Research and Extension Center (NEREC), Pine Tree Research Station (PTRS), and the Rice Research and Extension Center (RREC) during 2021.

	Grain Yield		
N Fertilizer Rate	**NEREC**†	**PTRS**	**RREC**
(lb N/ac)	**(bu./ac)**		
0	68 b‡	87 c	111 b
60	----	137 b	159 a
90	175 a	149 b	160 a
120	180 a	169 a	174 a
150	205 a	174 a	177 a
180	205 a	178 a	185 a
210	191 a	----	----

† NEREC = Northeast Research and Extension Center, Keiser, 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 13. Influence of nitrogen (N) fertilizer rate on the grain yield of PVL03 rice at the University of Arkansas System Division of Agriculture's Northeast Research and Extension Center (NEREC), Pine Tree Research Station (PTRS), and the Rice Research and Extension Center (RREC) during 2021.

	Grain Yield		
N Fertilizer Rate	**NEREC**†	**PTRS**	**RREC**
(lb N/ac)	**(bu./ac)**		
0	79 b‡	63 c	107 d
60	----	117 b	153 c
90	156 a	140 a	171 b
120	166 a	150 a	189 a
150	166 a	152 a	195 a
180	181 a	152 a	188 a
210	175 a	----	----

† NEREC = Northeast Research and Extension Center, Keiser, 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 ($P < 0.05$).

2021 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 2021 season, DD50 thermal unit accumulation, developmental data, and the effect of seeding date (SD) on grain and milling yield potential for 22 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 and milling yield were observed for all 22 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 twenty-six 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 on 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 (1/2 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 the 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, and 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 2021 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 Pine Tree Research Station (PTRS) near Colt, Ark., on a Calloway silt loam soil. Sixteen pure-line cultivars (ARoma 17, CLL15, CLL16, CLL17, CLM04, DG263L, DGL274, Diamond, Jewel, Jupiter, Lynx, ProGold1, ProGold2, PVL02, PVL03, 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 7301, RT 7321 FP, RT 7401, and RT 7521 FP) were seeded into plots of the same dimensions using the reduced seeding rate for hybrids (11 seeds/ft^2). The variety RTv7231 MA used a company-recommended seeding rate of 22 seed/ft^2. The SDs for 2021 were 22 March, 5 April, 20 April, 5 May, 20 May, and 4 June for the RREC, and 22 March, 5 April, 20 April, 6 May, 20 May, and 15 June for the PTRS. Standard cultural practices were followed according to the University of Arkansas System Division of Agriculture

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recommendations. A single preflood nitrogen (N) application of 130 lb N/ac was applied to all plots at the RREC, and 145 lb N/ac was applied to all plots at the PTRS 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 the 22 March, 20 April, and 20 May at the RREC location. At maturity, the 4 center rows in each plot were harvested, the 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/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). The study design was a randomized complete block with four 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 8–21 days at the PTRS and 6–18 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 2021 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 87 days for the 22 March to 30 for the 15 June SDs at PTRS and 67 days for the 22 March to 35 for the 4 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 2019 and 2020 (Clayton et al., 2020, 2021). The cultivars DG263L, PVL03, and RT 7321 FP required the fewest days and DD50 units to reach 0.5-in. IE with 49 days, and 1361, 1368, and 1361, DD50 units, respectively. Lynx and DGL274 required the most days and DD50 units to reach 0.5-in. IE with 84 and 85 days, respectively, and 1716 and 1752 DD50 units, respectively. The average days to 0.5-in. IE across planting dates was 67, and the average DD50 units across planting dates was 1566.

The average days needed to reach the developmental stage known as 50% heading from the time of emergence across SDs and cultivars was 90 days at the RREC and 91 days at the PTRS (Tables 4 and 5). The average time for cultivars to reach 50% heading ranged from 80 to 100 days at the RREC and from 73 to 108 days at the PTRS across SDs. For individual cultivars, the time required to reach 50% heading ranged from 111 days for DGL274 to 74 days for RTv7231 MA at the RREC. For the PTRS, the days to 50% heading ranged from 113 days for CLL16, ProGold1, and ProGold2 to 67 days for RT 7321 FP, RTv7231 MA, and Titan. For 2021, the thermal unit accumulation from emergence to 50% heading averaged 2356 DD50 units at the RREC and 2415 DD50 units at the PTRS. The individual cultivar thermal unit accumulation from emergence to 50% heading ranged from 2035 DD50 units for RT 7321 to 2696 DD50 units for CLL16, ProGrold1, and ProGold2 at the PTRS. For the RREC, thermal unit accumulation from emergence to 50% heading ranged from 2070 DD50 units for Diamond, Jewel, and ProGold1 to 2662 DD50 units for ProGold1. The lowest average thermal unit accumulation was the 22 March planting at the RREC and 15 June at the PTRS.

The average grain yield for 2021 at the RREC was 188 bu./ac and 173 bu./ac at the PTRS across SDs (Tables 6 and 7). The highest average grain yield across all cultivars was the 5 April and the 20 April SD at the PTRS and the 22 March SD at the RREC. The cultivar DG263L was the highest yielding variety at both locations and the hybrid RT 7401 yielded the highest at both stations.

The milling yields for 2021, averaged across SDs and cultivars, were 61/69 (%HR/%TR) at the RREC and 54/65 at the PTRS (Tables 8 and 9). The milling yields were higher for all the SDs at the RREC than the PTRS. This data is similar to 2019 and 2020 (Clayton et al., 2020, 2021).

Practical Applications

The data obtained during 2021 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 of Arkansas System Division of Agriculture personnel to help producers make decisions in regard to rice cultivar selection, in particular for early- and late-seeding situations.

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Literature Cited

Clayton, T.L., J.T. Hardke, D.L. Frizzell, R.J. Norman, W.J. Plummer, K.F. Hale, T.D. Frizzell, A. Ablao, K.A.K. Moldenhauer, and X. Sha. 2020. 2019 Degree-Day 50 (DD50) Thermal Unit Thresholds for New Rice Cultivars and Seeding Date Studies. *In*: B.R. Wells Rice Research Studies 2019. In K.A.K. Moldenhauer, B. Scott, and J. Hardke (eds.). University of Arkansas Agricultural Experiment Station Research Series 667:182-190.

Clayton, T.L., E. Castaneda-Gonzalez, J.T. Hardke, D.L. Frizzell, K.F. Hale, T.D. Frizzell, A. Ablao, K.A.K. Moldenhauer, and X. Sha. 2021. 2020 Degree-Day 50 (DD50) Thermal Unit Thresholds for New Rice Cultivars and Seeding Date Studies. *In:* J. Hardke, X. Sha, and N. Bateman (eds.). B.R. Wells Arkansas Rice Research Studies 2020. University of Arkansas Agricultural Experiment Station Research Series 676: 200-209.

Hardke, J. and R. Norman. 2018. DD50 Rice Management Program. *In:* J.T. Hardke (ed.) Arkansas Rice Production Handbook, University of Arkansas System Division of Agriculture Cooperative Extension Service. Little Rock, Ark. Publication MP 192, pp. 43-49.

Table 1. General seeding, seedling emergence, and flooding date information for the DD50 seeding date study in 2021 at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center near Stuttgart, Ark.

	Seeding Date					
	22 March	**5 April**	**20 April**	**5 May**	**20 May**	**4 June**
Emergence date	9 April	21 April	30 April	14 May	27 May	10 June
Flood date	28 May	3 June	23 June	30 June	30 June	9 July
Days from seeding to emergence	18	16	10	9	7	6
Days from seeding to flooding	67	59	64	56	41	35
Days from emergence to flooding	49	43	54	47	31	35

Table 2. General seeding, seedling emergence, and flooding date information for the DD50 seeding date study in 2021 at the University of Arkansas System Division of Agriculture's Pine Tree Research Station near Colt, Ark.

	Seeding Date					
	22 March	**5 April**	**20 April**	**6 May**	**20 May**	**15 June**
Emergence date	12 April	23 April	1 May	15 May	28 May	23 June
Flood date	17 June	17 June	17 June	2 July	2 July	15 July
Days from seeding to emergence	21	18	11	9	8	8
Days from seeding to flooding	87	73	58	57	43	30
Days from emergence to flooding	66	55	47	48	35	22

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 2021.

	Seeding Date							
	22 March		20 April		20 May		Average	
Cultivar	days	DD50 units	Days	DD50 units	days	DD50 units	days	DD50 units
ARoma 17	82	1671	73	1793	55	1514	70	1647
CLL16	79	1565	68	1656	51	1403	66	1541
CLL17	78	1534	69	1686	50	1396	66	1539
CLM04	81	1633	73	1796	56	1544	70	1658
DG263L	74	1440	67	1633	49	1361	64	1478
DGL274	85	1752	71	1732	53	1464	69	1649
Diamond	82	1656	71	1732	52	1443	68	1610
Jewel	82	1656	72	1774	53	1472	69	1634
Lynx	84	1716	76	1868	57	1597	72	1727
ProGold1	81	1625	71	1747	53	1478	68	1617
ProGold2	82	1648	73	1794	54	1507	70	1650
PVL02	78	1542	67	1627	50	1383	65	1517
PVL03	74	1436	63	1514	49	1368	62	1439
RT 7301	76	1478	65	1555	50	1376	63	1470
RT 7321 FP	73	1411	62	1493	49	1361	61	1421
RT 7401	78	1534	68	1656	50	1376	65	1522
RT 7521 FP	76	1490	66	1597	50	1397	64	1495
Mean	79	1576	69	1685	52	1437	67	1566
$LSD_{(\alpha=0.05)}$[a]	1.3	37.4	2.0	59.0	1.6	46.0	NS[b]	93.0

[a] LSD = least significant difference.
[b] NS = not significant.

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 2021.

	Seeding Date													
	22 March		5 April		20 April		5 May		20 May		4 June		Average	
Cultivar	days	DD50 units	days	DD50 units	days	DD50 units	days	DD50 units	days	DD50 units	days	DD50 units	days	DD50 units
ARoma 17	102	2305	96	2338	101	2585	91	2507	80	2248	83	2518	92	2417
CLL15	100	2241	94	2284	95	2423	88	2404	79	2242	79	2384	89	2330
CLL16	103	2319	98	2402	103	2639	94	2591	84	2393	85	2564	94	2485
CLL17	100	2233	92	2229	99	2546	89	2436	79	2243	79	2391	90	2346
CLM04	101	2262	93	2260	100	2569	90	2475	83	2349	81	2439	91	2392
DG263L	100	2241	92	2229	96	2455	88	2404	78	2188	78	2344	88	2310
DGL274	111	2499	97	2395	100	2584	93	2562	83	2356	83	2526	95	2487
Diamond	94	2070	93	2260	99	2532	91	2507	82	2318	80	2415	90	2350
Jewel	94	2070	92	2229	100	2564	90	2468	82	2318	79	2392	89	2340
Jupiter	103	2313	96	2338	100	2576	90	2468	82	2326	83	2502	92	2420
Lynx	101	2270	95	2323	100	2584	91	2491	82	2325	80	2423	92	2403
ProGold1	94	2070	98	2426	103	2662	95	2606	84	2380	83	2526	93	2445
ProGold2	103	2327	95	2331	103	2647	94	2584	83	2356	82	2470	93	2452
PVL02	99	2212	92	2213	97	2483	88	2404	77	2172	78	2352	88	2306
PVL03	101	2277	93	2268	100	2584	91	2491	82	2326	80	2415	91	2393
RT 7301	100	2227	93	2252	95	2432	88	2404	77	2172	78	2344	88	2305
RT 7321 FP	96	2136	91	2206	92	2324	87	2357	76	2132	77	2312	86	2244
RT 7401	100	2240	92	2229	99	2554	89	2436	78	2188	78	2368	89	2336
RT 7521 FP	100	2241	93	2252	97	2491	91	2492	82	2318	82	2486	91	2380
RTv7231 MA	95	2085	86	2050	91	2308	83	2249	74	2084	74	2232	84	2168
RT XP753	98	2185	92	2221	93	2377	89	2444	77	2180	79	2376	88	2297
Titan	96	2130	87	2091	94	2404	87	2373	77	2164	76	2304	86	2244
Mean	100	2225	93	2265	98	2515	90	2461	80	2263	80	2410	90	2356
$LSD_{(\alpha=0.05)}$[a]	1.5	43.6	1.5	47.2	2.0	60.4	1.6	50.8	1.6	50.4	1.6	50.0	4.7	71.8

[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 Pine Tree Research Station during 2021.

	Seeding Date													
	22 March		5 April		20 April		6 May		20 May		15 June		Average	
Cultivar	days	DD50 units	days	DD50 units	days	DD50 units	days	DD50 units	days	DD50 units	days	DD50 units	days	DD50 units
ARoma 17	111	2623	103	2598	95	2488	93	2637	84	2442	74	2258	93	2508
CLL15	106	2439	96	2401	93	2446	87	2450	81	2352	72	2202	89	2381
CLL16	113	2696	104	2636	96	2528	95	2704	88	2568	79	2370	96	2583
CLL17	109	2550	98	2465	92	2403	89	2522	78	2261	70	2135	89	2389
CLM04	109	2550	98	2465	94	2469	90	2570	83	2419	76	2304	92	2463
DG263L	109	2550	95	2377	90	2357	87	2450	79	2285	73	2229	89	2375
DGL274	111	2623	100	2526	95	2495	90	2562	83	2412	77	2328	93	2491
Diamond	107	2475	101	2556	93	2442	92	2613	84	2442	75	2292	92	2470
Jewel	109	2567	103	2598	95	2488	88	2498	84	2442	75	2287	92	2480
Jupiter	109	2550	99	2495	95	2508	88	2494	80	2330	74	2267	91	2441
Lynx	110	2587	101	2556	93	2446	92	2576	84	2442	76	2317	93	2487
ProGold1	113	2696	104	2636	96	2518	96	2728	87	2520	76	2309	95	2568
ProGold2	113	2696	104	2623	96	2528	96	2728	87	2520	74	2266	95	2560
PVL02	107	2494	98	2465	93	2446	87	2474	79	2285	69	2119	89	2380
PVL03	110	2587	97	2433	93	2449	88	2490	83	2419	76	2312	91	2448
RT 7301	104	2375	96	2401	90	2341	85	2398	78	2263	70	2150	87	2321
RT 7321 FP	102	2327	94	2345	88	2293	86	2496	76	2191	67	2035	85	2281
RT 7401	109	2550	98	2465	100	2357	91	2546	79	2285	75	2270	92	2404
RT 7521 FP	109	2550	98	2465	93	2449	90	2552	83	2412	71	2179	91	2435
RTv7231 MA	102	2327	94	2322	89	2325	86	2236	73	2103	67	2051	85	2260
RT XP753	106	2454	96	2401	90	2364	87	2466	78	2269	71	2164	88	2353
Titan	105	2407	97	2433	90	2339	87	2450	79	2285	67	2035	87	2325
Mean	108	2531	99	2485	93	2431	89	2461	81	2361	73	2222	91	2415
$LSD_{(\alpha=0.05)}$[a]	3.1	104.5	2.6	80.1	5.4	86.4	4.5	147.0	2.6	77.5	2.6	73.7	NS[b]	77.0

[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 2021.

Cultivar	Grain Yield by Seeding Date						Average
	22 March	5 April	20 April	5 May	20 May	4 June	
	---(bu./ac)---						
ARoma 17	179	168	130	162	115	151	151
CLL15	204	199	180	180	162	205	189
CLL16	215	206	164	178	145	172	180
CLL17	218	207	131	163	140	181	172
CLM04	212	201	163	182	142	184	180
DG263L	238	221	191	194	168	229	208
DGL274	212	209	173	182	161	208	191
Diamond	209	199	170	192	163	186	187
Jewel	192	175	150	185	126	166	166
Jupiter	222	169	160	166	126	166	168
Lynx	223	195	178	197	156	184	189
ProGold1	203	188	151	200	145	178	178
ProGold2	197	192	171	173	150	195	179
PVL02	174	127	137	148	132	159	147
PVL03	205	205	174	174	126	165	173
RT 7301	248	196	220	205	169	228	211
RT 7321 FP	247	219	204	222	201	233	221
RT 7401	243	209	233	218	199	236	223
RT 7521 FP	237	209	205	187	199	239	212
RTv7231 MA	224	212	206	198	168	227	206
RT XP753	246	215	212	228	192	238	222
Titan	233	176	181	177	140	195	183
Mean	217	195	177	187	156	197	188
$LSD_{(\alpha=0.05)}$[a]	16.8	24.6	20.7	16.2	21.3	18.7	7.8

[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 Pine Tree Research Station during 2021.

Cultivar	Grain Yield by Seeding Date						Average
	22 March	5 April	20 April	6 May	20 May	15 June	
	-------(bu./ac)-------						
ARoma 17	155	162	154	149	148	126	149
CLL15	194	195	210	179	164	150	182
CLL16	166	179	175	155	188	152	169
CLL17	174	177	183	156	154	146	165
.CLM04	178	177	175	120	145	136	156
DG263L	204	205	210	175	192	173	193
DGL274	195	209	190	171	184	173	187
Diamond	169	178	173	163	176	166	171
Jewel	144	158	163	133	160	143	150
Jupiter	182	179	163	142	141	152	161
Lynx	197	202	207	158	174	143	182
ProGold1	158	176	171	148	174	155	164
ProGold2	167	167	178	157	160	156	164
PVL02	171	167	156	131	109	98	138
PVL03	163	160	170	121	115	52	130
RT 7301	220	218	204	187	191	157	196
RT 7321 FP	209	199	200	173	174	159	188
RT 7401	218	241	231	211	202	180	214
RT 7521 FP	206	212	220	189	178	166	195
RTv7231 MA	212	210	210	205	173	171	197
RT XP753	215	224	219	199	187	166	202
Titan	167	156	193	143	137	142	157
Mean	185	189	189	163	165	148	173
$LSD_{(\alpha=0.05)}$[a]	14.0	29.2	17.9	25.1	30.1	22.5	9.5

[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 2021.

	Milling Yield by Seeding Date						
Cultivar	**22 March**	**5 April**	**20 April**	**5 May**	**20 May**	**4 June**	**Average**
	----------(%HR/%TR)[a]----------						
ARoma 17	64/70	64/69	63/69	61/68	60/68	68/72	63/69
CLL15	60/68	62/68	58/67	58/66	56/66	63/70	59/68
CLL16	57/67	59/67	58/67	60/67	61/69	65/71	60/68
CLL17	61/67	61/67	61/68	59/67	56/66	63/70	60/67
CLM04	64/68	65/69	64/68	64/68	62/69	68/71	64/69
DG263L	56/66	56/66	59/67	58/66	59/66	63/69	58/67
DGL274	57/63	58/65	61/67	60/65	59/65	63/68	59/66
Diamond	58/69	59/69	58/68	57/68	58/68	67/72	59/69
Jewel	54/68	56/69	58/68	58/69	62/70	67/72	59/69
Jupiter	61/66	63/67	62/66	63/68	60/66	67/71	63/67
Lynx	64/69	63/68	64/69	63/68	60/68	67/71	64/69
ProGold1	60/68	62/68	60/67	60/68	60/69	68/72	62/69
ProGold2	58/70	61/70	59/67	56/68	58/69	66/73	60/69
PVL02	63/71	65/72	64/71	63/70	62/70	65/72	64/71
PVL03	59/71	63/71	59/69	57/68	56/68	66/73	60/70
RT 7301	60/70	60/70	60/70	63/70	57/69	66/72	61/70
RT 7321 FP	57/69	56/69	57/69	61/70	58/69	65/72	59/70
RT 7401	58/69	58/69	61/69	62/70	58/69	67/72	61/69
RT 7521 FP	58/68	60/68	61/69	62/69	61/69	68/73	61/69
RTv7231MA	58/67	58/68	60/70	58/68	57/67	63/70	59/68
RT XP753	59/70	60/69	60/70	63/70	59/69	67/73	61/70
Titan	65/69	64/69	65/70	65/69	61/67	68/71	65/69
Mean	60/68	61/68	61/68	61/68	59/68	66/71	61/69
$LSD_{(\alpha=0.05)}$ %HR[b]	1.5	1.6	2.0	1.8	2.0	1.5	0.7
$LSD_{(\alpha=0.05)}$ %TR	0.7	1.0	1.3	0.9	1.1	0.7	0.4

[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 University of Arkansas System Division of Agriculture's Pine Tree Research Station during 2021.

	Milling Yield by Seeding Date						
Cultivar	**22 March**	**5 April**	**20 April**	**6 May**	**20 May**	**15 June**	**Average**
	(%HR/%TR)[a]						
ARoma 17	62/69	60/69	60/69	53/64	51/61	61/68	58/67
CLL15	61/68	56/67	56/67	48/61	45/57	60/68	54/65
CLL16	53/65	54/66	53/65	50/62	52/63	54/66	53/65
CLL17	63/69	60/68	59/67	53/63	47/57	55/65	56/65
CLM04	65/69	61/69	62/68	52/62	50/60	64/68	60/66
DG263L	57/66	54/65	55/65	50/61	47/56	56/65	53/63
DGL274	57/65	57/67	56/65	50/60	46/56	59/66	54/63
Diamond	56/67	54/68	56/68	54/65	55/64	62/69	56/67
Jewel	52/67	54/67	56/68	56/66	55/63	63/70	56/67
Jupiter	62/67	56/67	61/66	50/60	47/56	63/68	56/64
Lynx	65/69	59/68	60/68	52/62	45/58	62/68	57/65
ProGold1	60/69	58/68	59/68	52/63	52/61	63/70	57/67
ProGold2	60/69	57/69	57/68	51/63	50/61	60/69	56/66
PVL02	65/71	62/71	62/70	53/65	51/62	61/68	59/68
PVL03	59/70	56/69	56/68	46/63	41/57	38/57	51/65
RT 7301	61/70	50/69	51/68	51/63	43/59	56/67	52/66
RT 7321 FP	58/69	49/68	50/67	47/61	38/56	52/66	49/64
RT 7401	61/69	54/68	54/68	46/60	43/56	59/68	53/65
RT 7521 FP	58/67	54/66	55/65	46/59	42/55	58/67	52/63
RTv7231 MA	58/69	48/69	50/69	54/65	48/59	59/68	53/66
RT XP753	60/70	49/68	48/68	47/61	40/57	54/67	50/65
Titan	63/69	52/69	55/68	55/63	42/56	58/66	54/66
Mean	60/68	55/68	56/67	51/62	47/59	58/67	54/65
$LSD_{(\alpha=0.05)}$ %HR[b]	2.2	4.4	3.3	4.8	5.9	6.1	1.6
$LSD_{(\alpha=0.05)}$ %TR	1.0	1.0	1.1	2.8	3.7	3.0	0.9

[a] %HR/%TR = percent head rice/percent total rice.

[b] LSD = least significant difference.

Performance of Twelve Rice Cultivars in a Furrow-Irrigated Rice (FIR) System, 2021

D.L. Frizzell,[1] J.T. Hardke,[1] L.R. Amos,[1] E. Castaneda-Gonzalez,[1] and T.L. Clayton[1]

Abstract

In the last several years, there has been increasing interest in furrow-irrigated rice (FIR) (*Oryza sativa* L.) production. Cultivar selection recommendations have been general and primarily based on anecdotal evidence to date. In 2021, a small-plot rice cultivar performance trial was established at Jackson Co. on a Dundee silt loam soil. A split-plot design was utilized with the whole-plot factor being the location within the field (top and bottom) and the split-plot factor being cultivar, of which there were 12 evaluated. In 2021, the bottom area of the field had significantly higher yields than the top area of the field. In general, the hybrid cultivars RT XP753, RT 7521 FP, and RT 7401 had significantly higher grain yields than the other entries in the trials at both top and bottom areas of the fields. Jupiter, Lynx, and CLL17 had greater head rice yields than all other entries at the top of the field. Jupiter and Lynx also had the highest head rice yields at the bottom of the field. As plot areas were uniformly managed, additional research is necessary to determine whether varieties can be more competitive with the hybrids when cultivar-specific management practices are implemented.

Introduction

Rice acreage utilizing the furrow-irrigated rice (FIR) system continues to increase in Arkansas. Since 2018, over 100,000 acres in Arkansas have been grown using the system. A dramatic increase was noted during 2020, with FIR system acres reaching an estimated 244,198 (Hardke, 2021). Limited research has been conducted on current rice cultivars for their performance in a FIR production system. Hybrid cultivars have been suggested as more reliable options in a FIR system due to their disease resistance traits and larger root systems, which may provide improved stress management. In addition, hybrid cultivars have been noted for their increased efficiency in nitrogen uptake compared to pure-line varieties (Norman et al., 2013), which may be increasingly beneficial in a FIR system. In general, hybrid cultivars are recommended in FIR systems primarily based on observation and anecdotal evidence. Newer pure-line varieties may also be of interest for use in the FIR system.

Procedures

A field study was located at a commercial farm in Jackson County near Newport, Ark., in 2021 on a Dundee silt loam utilizing a 30-in. furrow spacing (Table 1). The plot design was a split-plot, with the whole-plot factor being the location within the field (top, where upland conditions existed, and bottom, where flooded conditions generally existed) and the split-plot factor being cultivar. Cultivars tested during 2021 included the varieties CLL15, CLL16, CLL17, DG263L, Diamond, Jewel, Jupiter, Lynx, and Titan, and the hybrids RT XP753, RT 7521 FP, and RT 7401. Each plot was 4 beds (10 ft) in width and 17 ft in length. Drill row spacing was 7.5 inches. The previous crop was soybean [*Glycine max* (L.) Merr.].

Field management was consistent with the University of Arkansas System Division of Agriculture recommendations. Irrigation events occurred every 4–7 days during the growing season. The top of the field was generally saturated across each bed row with each irrigation event, and a 4- to 8-in. flood was maintained at the bottom of the field. At maturity, a single bed row (30-in. harvest width) was harvested, the moisture content and weight of the grain were determined, and a subsample of harvested grain was removed for milling purposes. Grain yields were adjusted to 12% moisture and reported on a bushels per acre (bu./ac) basis. A bushel of rice weighs 45 lb. The dried rice was milled using a PAZ/1-DTA laboratory rice mill (Zaccaria, USA) to obtain percent head rice (%HR, whole kernels) and percent total white rice (%TR) to provide a milling yield expressed as %HR/%TR. Data were analyzed using PROC GLMMIX in SAS v. 9.4 (SAS Institute, Inc. Cary, N.C.), and grain yield means were separated at an alpha level of 0.05.

Results and Discussion

In 2021, there was a location by cultivar interaction at Jackson Co. ($P < 0.05$). Therefore, data were analyzed by location (top and bottom). At the top of the field, RT XP753 and RT 7401 had similar grain yields, and RT 7521 FP had a similar grain yield to RT 7401 but was not similar to RT XP753 (Table 2). These 3 hybrids had significantly higher grain yield compared to all other cultivars tested. However, the varieties DG263L and Jupiter each yielded greater than 200 bu./ac at the top of the field. Jupiter, Lynx, and CLL17 had greater head rice yields than all other entries at the top of the field. At the bottom of the Jackson Co. site, RT 7401, RT XP753, and RT 7521 FP had significantly higher grain yields than all other cultivars tested. Jupiter and Lynx had the highest head rice yields of all the cultivars. At the bottom of

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the field, grain yield and head rice yields of each cultivar were generally greater than the top of the field. Total rice yields were generally similar between the top and bottom locations at this site during 2021. The hybrids RT XP753 and RT 7401 performed equally well at both locations in the field during 2021 in regard to grain yield. Jupiter and Lynx had the highest head rice yields, and RT XP753 and RT 7401 had the highest total rice yields at both locations in the field.

The Jackson Co. field was cropped to the hybrid RT XP753. Therefore, plots were uniformly managed to optimize hybrid rice production. Additional research is needed to determine whether varieties can be more competitive with hybrids when cultivar-specific management practices are implemented.

Practical Applications

The 2021 FIR cultivar performance trials provide additional data to producers interested in the FIR production system. The trials also provide valuable information on cultivar performance in the uppermost non-flooded area of the field versus the bottom end of the field where continuously saturated soil conditions exist.

Acknowledgments

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Literature Cited

Hardke, J.T. 2021. Trends in Arkansas rice production, 2020. *In*: J. Hardke, X. Sha, and N. Bateman (eds.). B.R. Wells Arkansas Rice Research Studies 2020. University of Arkansas Agricultural Experiment Station Research Series 676:11-18.

Norman, R.J., T. Roberts, N. Slaton, and A. Fulford (2013). Nitrogen uptake efficiency of a hybrid compared with a conventional, pure-line rice cultivar. Soil Sci. Soc. Amer. J. 77(4):1235-1240.

Table 1. Agronomic information for a furrow-irrigated rice (FIR) cultivar trial located in Jackson County during 2021.

Soil classification	Dundee silt loam
Planting date	14 May
Emergence date	26 May
Harvest date	24 September
Nitrogen management	Pre-irrigation: 300 lb N-(n-butyl) thiophosphoric triamide (NBPT) coated urea

Table 2. Results of Jackson County Furrow-Irrigated Rice Trial during 2021. Planted 14 May. Harvested 24 September.

Cultivar	Grain Length†	Location	Lodging‡	Moisture§	Grain Yield	Milling Yield¶
			(%)	(%)	(bu./ac)	(%HR/%TR)
Diamond	L	Top	0	12.9 f#	174 fg	54/70
Jewel	L	Top	0	14.0 de	172 g	61/71
DG263L	L	Top	0	13.5 ef	209 c	56/69
CLL15	L	Top	0	13.0 f	181 fg	59/67
CLL16	L	Top	0	16.7 b	198 cde	61/70
CLL17	L	Top	0	14.9 c	187 def	63/70
Jupiter	M	Top	0	20.8 a	201 cd	65/70
Titan	M	Top	0	13.4 ef	182 fg	61/70
Lynx	M	Top	0	17.6 b	184 efg	64/69
RT XP753	L	Top	0	14.6 cd	258 a	58/72
RT 7521 FP	L	Top	12.5	13.6 ef	233 b	59/71
RT 7401	L	Top	0	14.6 c	244 ab	62/72
P-value $(\alpha=0.05)$			NS	<0.0001	<0.0001	<0.0001/<0.0001
Diamond	L	Bottom	0	16.6 ef	210 c	62/70
Jewel	L	Bottom	0	18.4 c	190 e	66/71
DG263L	L	Bottom	0	16.2 ef	210 c	63/70
CLL15	L	Bottom	0	18.0 cd	227 b	66/71
CLL16	L	Bottom	0	20.3 b	223 b	65/71
CLL17	L	Bottom	0	17.2 de	198 de	65/70
Jupiter	M	Bottom	7.5	22.3 a	193 e	67/71
Titan	M	Bottom	0	14.6 hi	192 e	66/70
Lynx	M	Bottom	15.0	17.0 de	203 cd	67/71
RT XP753	L	Bottom	0	13.9 i	258 a	65/72
RT 7521 FP	L	Bottom	0	15.9 fg	252 a	65/71
RT 7401	L	Bottom	0	15.1 gh	259 a	65/72
P-value $(\alpha=0.05)$			NS††	<0.0001	<0.0001	<0.0001/<0.0001

† Grain length: L = long-grain; M = medium-grain.
‡ Lodging = % of plot down at harvest.
§ Grain moisture at harvest.
¶ Milling yield = % Head Rice/% Total Rice.
# Means within a column followed by the same letter are not significantly different (*P* < 0.05).
†† NS = not significant.

Impact of Harvest Row Selection on Grain Yield in Small Plot Rice Research

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Abstract

A study was initiated in 2021 to determine the effect of harvest row selection on small-plot rice research harvest data. The rice cultivars CLL16, Diamond, Titan, and RT XP753 were drill seeded at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center. A Wintersteiger Classic small plot combine was used to harvest all plots. The treatments consisted of the harvest of specific rows of each cultivar with the direction of travel remaining constant and included harvesting rows 3–6, 1–8, 2–8, and 3–8 from each 8-row plot. Grain yield was influenced by harvest treatment during this study year, with the harvest of the center 4 rows resulting in the lowest grain yield of the 4 treatments.

Introduction

The plot area for small-plot rice research is generally carried out using a plot area consisting of the width of the grain drill (~5 feet) and a managed plot length of 12 to 25 feet. Cultural practices and management are carried out as similarly to large-scale production fields as possible. At harvest, selected rows are harvested from each plot, and the total harvest weight of grain per area harvested is adjusted to a dry-weight standard of 12% moisture. This number is then converted from lb/ft^2 to the reporting standard in Arkansas of bushels per acre (bu./ac). A factor that can influence crop yield is the "edge effect." This has been noted in the literature for most crops and operates under the premise that competition for crop inputs such as light, space, water, and nutrients is less along the edge of a given area and, therefore, the plants on the border of that area have the potential to yield more than their neighbors. In order to help mitigate this effect, one common practice is to seed a large enough area so that at harvest, only the center of the plot is harvested. This is generally thought to provide yield numbers that are more similar to those observed in production fields. This has been carried out in small-plot rice research by the use of aftermarket crop dividers enabling only the center rows to be collected or adjusting the combine path to harvest all but 1 or 2 rows of each plot. It is unclear as to the impact of harvest row selection on small-plot rice grain yield.

Procedures

A study was initiated in 2021 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 previously cropped to soybean [*Glycine max* (L.) Merr.]. The study was seeded on 27 May with the pure-line cultivars CLL16, Diamond, and Titan at a seeding rate of 33 $seed/ft^2$, and the hybrid cultivar RT XP753 was seeded at 11 $seed/ft^2$ in plots 8 rows wide (7.5-in. spacing) and 17.5-ft long. All seed was treated with CruiserMaxx Rice seed treatment (insecticide + fungicides) plus Vibrance fungicide and also Zinche® seed treatment containing 32.5% zinc oxide. Cultural practices otherwise followed recommended practices for maximum yield. In order to aid harvest efficiency, each of the 4 cultivars was seeded into plots arranged in a consecutive manner in the test representing 1 replication of each of the 4 harvest structures. The distance between plot ends was 30 inches. The distance between plot sides was 28 inches. The experimental design for each cultivar was a randomized complete block design with 4 replications. A Wintersteiger Classic small plot combine was used to harvest all plots. The treatments consisted of the harvest of specific rows of each cultivar with the direction of travel remaining constant (Table 1). Without any modifications, the original combine crop dividers allow for the harvest of the entire width of an 8-row plot (Treatment 2). Treatments 3 and 4 were accomplished by adjusting the combine path to leave 1 or 2 rows unharvested, respectively. Treatment 1 required the use of modified crop dividers that allow full range of motion for the header and cutter bar but only allowed 4 of the 7.5-in. rows to enter the header. All unharvested rows in each treatment were pressed to the soil surface by the combine tracks. At the time of harvest on 9 October, the moisture content and weight of the grain were determined, and a subsample of harvested grain was removed for milling purposes. Grain yields were calculated based on the area harvested, adjusted to 12% moisture, and reported on a bushels per acre (bu./ac) basis. A bushel weighs 45 lb. The dried rice was milled using a PAZ/1-DTA laboratory rice mill (Zaccaria, USA) to obtain percent head rice (%HR, whole kernels) and percent total white rice (%TR) to provide a milling yield expressed as %HR/%TR. Data were analyzed using GLMM, PROC GLMMIX, SAS v. 9.4 (SAS Institute, Inc., N.C.) with means separated at a *P*-value of 0.05.

Results and Discussion

There was no treatment by cultivar interaction during 2021; only the main effects of treatment and cultivar significantly influenced rice grain yield during this study year (Table 2). Grain yield was similar between treatments 3 and 4 when harvesting either 6 or 7 rows of each plot. Harvesting 8 rows of each plot (treatment 2) resulted in grain yield similar to that of harvesting 7 rows but

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was less than harvesting the 6 rows of treatment 4. Harvesting the 4 center rows (treatment 1) resulted in grain yield lower than any of the other treatments. Overall, the grain yield of RT XP753 was greatest, followed by CLL16 and Diamond, then Titan during 2021. This initial dataset suggests harvest of the center 4 rows of an 8-row plot seeded at 7.5-in. row spacing may provide a lower calculated grain yield compared to the other treatment structures. Additional studies are needed to determine the influence of harvest row selection on rice grain yields.

Practical Applications

While the results reported here are from only a single site-year of study, they will be used to provide guidance to future studies aimed at improving small-plot rice research.

Acknowledgments

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Table 1. Treatment structure based on an 8-row plot seeded on 7.5-in. row spacing. Harvested 9 October at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC) near Stuttgart, Ark., during 2021.

Treatment	Rows Harvested[a]	Rows Remaining[a]
1	3–6	1 and 2; 7 and 8
2	1–8	none
3	2–8	1
4	3–8	1 and 2

[a] Direction of travel was west to east. All rows not harvested were separated from the harvested rows by the combine crop dividers.

Table 2. Impact of selected harvest rows on rice grain yield at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC) near Stuttgart, Ark., during 2021.

	Harvested Rows				
Cultivar	Rows 3–6 (T1)	Rows 1–8 (T2)	Rows 2–8 (T3)	Rows 3–8 (T4)	Cultivar Mean
	----------Grain Yield (bu./ac)----------				
CLL16	185	206	219	220	207 b[a]
Diamond	192	209	215	207	206 b
Titan	152	176	182	184	173 c
XP753	225	239	242	257	241 a
Treatment Mean	187 c[b]	207 b	213 ab	216 a	
Treatment *P*-value		<0.0001			
Cultivar *P*-value					<0.0001

[a] Mean of each cultivar averaged across treatments, means followed by the same letter are not significantly different at the α = 0.05 level.

[b] Mean of each treatment averaged across cultivars, means followed by the same letter are not significantly different at the α = 0.05 level.

Effect of Plot Length on Rice Harvest Data

D.L. Frizzell,[1] J.T. Hardke,[1] T.L. Clayton,[1] E. Castaneda-Gonzalez,[1] and L.R. Amos[1]

Abstract

A study was initiated in 2021 to determine the effect of plot length on small-plot rice research harvest data. The rice cultivars CLL16 and RT XP753 were seeded into 2 separate blocks of a paddy at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center near Stuttgart, Ark. Prior to flooding, individual plots were established within each block to create plot lengths of 8, 12, 16, 20 or 24 ft. The plot width remained constant at 5 ft. Plot length influenced the grain yield of CLL16 but not RT XP753 during 2021. Plot length did not influence the percent head rice or the total rice of either cultivar during this study year.

Introduction

Rice small-plot research is generally carried out using a plot area consisting of a single width of the grain drill and a length based on such factors as the available study area, seed availability, or treatment inputs and generally uses a managed plot length of 12 to 25 feet. This length can vary between research programs due to the above-mentioned factors. The plots may also be managed throughout the growing season at a longer length than the plot ends trimmed just prior to harvest to provide a larger alley for the plot combine to process the harvested grain before entering into the next plot in a harvest sequence. With the calculations involved to convert harvested plot weight of rice from a 50–100 ft^2 area up to the reporting standard in Arkansas of bushels per acre (bu./ac), the question has become what is an adequate plot length for rice small-plot agronomic research to minimize over/underestimation of rice grain yield.

Procedures

A study was initiated 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 previously cropped to soybean [*Glycine max* (L.) Merr.]. The rice cultivars CLL16 and RT XP753 were seeded 27 May at 33 and 11 seed/ft^2, which is within the recommended range of seeding rate for a variety or hybrid cropped to a well-prepared silt loam soil. All seed was treated with CruiserMaxx Rice seed treatment (insecticide + fungicides) plus Vibrance fungicide and also Zinche® seed treatment containing 32.5% zinc oxide.

The study was contained within a single bay to streamline management practices for the study; however, both cultivars were blocked separately within the bay. Each cultivar was seeded in a continuous fashion within its respective block in passes that were 8 rows (7.5-in. spacing) wide. Cultural practices otherwise followed recommended practices for maximum yield. Prior to flooding, individual plots were established by glyphosate application (2.5 ft width) across specific areas of each pass to create plot lengths of 8, 12, 16, 20, or 24 feet. Each plot length was then repeated randomly within each pass of each cultivar. The experimental design for each cultivar was a randomized complete block design with 4 replications.

The center 4 rows of each plot were harvested on 8 October using a Wintersteiger Classic small plot combine, the moisture content and weight of the grain were determined, and a subsample of harvested grain was removed for milling purposes. Grain yields were adjusted to 12% moisture and reported on a bushel per acre (bu./ac) basis. A bushel weighs 45 lb. The dried rice was milled using a PAZ/1-DTA laboratory rice mill (Zaccaria, USA) to obtain percent head rice (%HR, whole kernels) and percent total white rice (%TR) to provide a milling yield expressed as %HR/%TR. Data were analyzed using GLMM, PROC GLMMIX, SAS v. 9.4 (SAS Institute, Inc., N.C.) with means separated at a *P*-value of 0.05.

Results and Discussion

Plot length influenced grain yield of CLL16 but not RT XP753 during 2021 (Table 1). Plot lengths of 16, 20, or 24 feet resulted in a similar grain yield for CLL16. Grain yields were similar between plot lengths of 8 or 12 ft. Grain yield of 8 or 12 ft plots was greater than the longer plot lengths suggesting an overestimation of calculated grain yield when plots of this length are used for this variety. Although not significant during this study year, the grain yield of RT XP753 was numerically lower with plot lengths of 16 and 24 feet compared to those with plot lengths of 8, 12, and 20 feet. Given these differences in results between the selected cultivars, additional research is needed on these and other cultivars to determine whether effects of plot length are cultivar or plant-type specific. Plot length did not influence percent head rice or total rice of either cultivar during this study year. As this is an initial study year, more data is needed to determine the influence of plot length on rice grain and milling yields.

Practical Applications

While the results reported here are from only a single site-year of study, they will be used to provide guidance to future studies aimed at improving small-plot rice research.

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Table 1. Impact of plot length on rice grain yield and milling yield at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC) near Stuttgart, Ark., during 2021.

	Grain Yield		Milling Yield[a]	
Plot Length	**CLL16**	**RT XP753**	**CLL16**	**RT XP753**
(ft)	-----------------(bu./ac)---------------		-------------(%HR/%TR)-------------	
8	200 a[b]	213	60/68	60/69
12	193 a	219	61/69	60/69
16	169 b	204	59/68	60/69
20	171 b	214	60/68	59/69
24	160 b	205	60/68	60/70
P-value $_{(\alpha=0.05)}$	0.0119	0.6476	0.4785/0.4002	0.5302/0.6883

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

[b] Means followed by the same letter within a column are not significantly different at α = 0.05.

2021 Rice Grower Research and Demonstration Experiment Program

J.T. Hardke[1] *and E. Castaneda-Gonzalez*[1]

Abstract

In 2021, the Rice Grower Research and Demonstration Experiment (GRADE) Program was located in Arkansas County near Stuttgart, Ark., Craighead County near Harrisburg, Ark., and Lee County near Moro, Ark. Trials consisted of replicated, large-block demonstrations evaluating the rice varieties Diamond, CLL15, CLL16, and Jewel. The University of Arkansas System Division of Agriculture and the Arkansas Rice Research and Promotion Board first initiated this program in 2017 to conduct replicated large block field trials consisting of replicated plots of approximately one-half acre or larger on grower farms to bridge information between small plot research trials and grower field experiences. It is a collaborative effort between growers, consultants, county extension agents, extension specialists, and researchers.

Introduction

The Rice Grower Research and Demonstration Experiment (GRADE) Program has continued to grow and develop since it began in the 2017 growing season when it was established by the University of Arkansas System Division of Agriculture's Cooperative Extension Service and the Arkansas Rice Research and Promotion Board. The purpose is to coordinate and demonstrate large-scale plots to endorse the performance of rice recommendations and cultivars in commercial production fields across the Arkansas production region. This program's overall objective is to increase confidence and visibility of research as well as bridge the gap between small-plot research trials and whole-field verification program demonstrations.

The goals of the Rice GRADE Program are to 1) execute large-scale trials on commercial rice farms; 2) increase large-plot research data on cultivar performance; 3) arrange hands-on training of agents, consultants, and growers; and 4) produce data to support the development of rice budgets, computer-assisted management programs, agronomic practices, resource utilization, and statewide rice extension programs.

Demonstrations of this type allow more hands-on participation by county agents, consultants, and others while providing multiple sites for educational field events. Additional benefits include the ability to provide supplemental information to the verification program as well as allowing more growers opportunities to evaluate and provide input on practices at a larger scale than small-plot research in multiple counties across the state. Long-term, the success of this program should result in the adoption of lower risk recommended practices and increase whole farm revenue.

Procedures

Prior to planting, fields were selected for involvement in the Rice GRADE Program for the 2021 season. Variety demonstration trials in 2021 were located in Arkansas, Craighead, and Lee Counties and included the cultivars CLL15, CLL16, Diamond, and Jewel. Each location was seeded with a John Deere 6120E tractor and an 8-ft Great Plains no-till box drill (7.5-in. row spacing). Based on harvest equipment size and field layout, each variety demonstration plot ranged in size from 32–40 ft. wide and 300–500 ft. in length. A randomized complete block design with 4 replications was used for all trials.

Throughout the growing season, periodic visits were made to each location by the program coordinator to monitor the growth and development of the crop and to collect data. In addition to inputs from the program coordinator, county agent, and rice extension agronomist, the overall management of the trial area is based on standard grower practices for that farm.

The demonstrations compared the varieties Diamond, CLL15, CLL16, and Jewel planted at the standard recommended seeding rate of approximately 30 seed/ft^2. Harvest was completed within each plot using cooperator combine harvesters and grain weight was determined with a weigh wagon. Grain yield was corrected to 12% moisture and reported in bushels per acre (bu./ac). Samples were collected at the weigh wagon to evaluate grain harvest moisture and test weight, then dried to 12% moisture to evaluate milling yields of percent head rice (%HR) and total milled rice (%TR) reported as %HR/%TR. Data were analyzed using PROC GLIMMIX in SAS v. 9.4 (SAS Institute, Inc., Cary, N.C.), and means were separated using least-square means at an $\alpha = 0.10$.

Results and Discussion

In the Arkansas County variety demonstration, Jewel, Diamond, and CLL16 produced higher grain yields compared to CLL15 (Table 1). CLL16 and Diamond had higher harvest moistures than CLL15 or Jewel. While there were no differences in head rice milling yield, Diamond produced higher total rice milling yields compared to CLL15 and CLL16.

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In the Lee County variety demonstration, CLL16 produced higher grain yields compared to CLL15 and Jewel, but not Diamond (Table 2). Jewel had higher head rice milling yields compared to CLL15 and Diamond, but not CLL16. For total rice milling yields, Diamond produced higher values compared to CLL15 and CLL16. For grain moisture at harvest, CLL16 had values higher than all other cultivars.

At the Poinsett County variety demonstration, there were no differences for any factors evaluated (Table 3). Considerable plot-to-plot variation was observed at this location. However, grain yields remained over 180 bu./ac for all cultivars and produced the highest head rice milling yields of all locations.

A summary of results across all demonstration sites can be found in Table 4. No differences were observed between cultivars when averaged across all locations. This highlights the variability in area-specific performance of individual cultivars. While the overall average suggests no differences, it is clear that certain cultivars can outperform others at the individual sites.

Practical Applications

Data collected from the 2021 Rice GRADE Program provide support for data produced from small-plot research. This information can be used to aid in cultivar selection by Arkansas rice producers.

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Table 1. Arkansas County Variety Demonstration near Stuttgart, Arkansas in 2021.

Cultivar	Harvest Moisture	Test Weight	Grain Yield	Head Rice	Total Rice
	(%)	(lb/bu.)	(bu./ac)	(%)	(%)
CLL15	17.7 b†	39.7 b	186.5 b	54.4	63.6 c
CLL16	19.1 a	45.0 a	196.8 a	53.8	64.3 bc
Diamond	18.8 a	39.8 b	198.9 a	54.6	65.7 a
Jewel	17.6 b	41.0 ab	204.8 a	53.9	64.9 ab
P-value	0.0250	0.0609	0.0143	0.5879	0.0309

† Means within a column followed by the same letter are not significantly different ($P > 0.1$).

Table 2. Lee County Variety Demonstration near Marianna, Arkansas in 2021.

Cultivar	Harvest Moisture	Test Weight	Grain Yield	Head Rice	Total Rice
	(%)	(lb/bu.)	(bu./ac)	(%)	(%)
CLL15	13.9 c†	40.3	176.9 b	52.8 b	66.8 c
CLL16	16.1 a	42.4	197.6 a	53.6 ab	67.4 bc
Diamond	14.8 b	42.0	189.7 ab	53.3 b	68.3 a
Jewel	14.1 bc	41.5	177.0 b	56.0 a	67.9 ab
P-value	0.0005	0.1277	0.0699	0.0779	0.0034

† Means within a column followed by the same letter are not significantly different ($P > 0.1$).

Table 3. Poinsett County Variety Demonstration near Harrisburg, Arkansas in 2021.

Cultivar	Harvest Moisture	Test Weight	Grain Yield	Head Rice	Total Rice
	(%)	(lb/bu.)	(bu./ac)	(%)	(%)
CLL15	17.1	37.9	195.0	59.0	66.7
CLL16	16.3	37.0	190.0	57.9	64.6
Diamond	17.4	34.8	182.8	55.3	63.5
Jewel	17.7	39.8	183.9	60.1	66.9
P-value	0.4778	0.1375	0.6003	0.2863	0.1943

Table 4. Summary of County Variety Demonstrations, 2021.

Cultivar	Harvest Moisture	Test Weight	Grain Yield	Head Rice	Total Rice
	(%)	(lb/bu.)	(bu./ac)	(%)	(%)
CLL15	16.2	39.3	186.1	55.4	65.7
CLL16	17.2	41.4	195.4	54.8	65.5
Diamond	17.0	39.4	191.4	54.3	66.0
Jewel	16.4	40.7	189.1	56.4	66.5
P-value	0.5347	0.2595	0.4098	0.3596	0.6545

Comparison of Seeding and Bedding Methods for Furrow-Irrigated Rice

J.T. Hardke,[1] J.L. Chlapecka,[1] B.L. Wright,[1] E. Castaneda-Gonzalez,[1] D.L. Frizzell,[1] and T.L. Clayton[1]

Abstract

Furrow-irrigated rice (FIR) acreage is rapidly increasing across Arkansas. Acreage has risen from approximately 10,000 acres in 2015 to over 240,000 acres in 2020. The rapid increase in FIR acres has also resulted in a wide range of practices used to implement FIR. Therefore, a study was designed to assess 4 different methods of seeding and/or seedbed preparation for FIR. Treatments include 1) drilling seed into flat soil followed by creating water furrows post-seeding, 2) forming beds/furrows followed by drilling seed into the previously formed beds, 3) drilling seed into flat soil followed by forming beds/furrows post-seeding over the top of seed, and 4) broadcasting seed on the soil surface followed by forming beds post-seeding. Trials were conducted on both a silt loam and clay soil. At the silt loam site, broadcasting seed followed by forming beds produced significantly higher grain yields compared to drilling flat followed by water furrows and forming beds followed by drilling. Drilling flat followed by forming beds performed similarly to the broadcast treatment. At the clay site, drilling flat followed by water furrows resulted in significantly higher grain yields compared to all other treatments. Differences between sites could be related to soil type and/or equipment available to perform operations, but further study is needed to quantify these differences.

Introduction

Rice acreage utilizing the furrow-irrigated rice (FIR) system continues to increase in Arkansas and throughout the mid-South. As recently as 2015, FIR acres in Arkansas totaled as few as 11,000 acres (Hardke, 2016). Since that time, interest has rapidly increased with acres reaching over 240,000 acres in 2020 (Hardke, 2021). This rapid increase has occurred without available research into the most effective seeding and bedding methods for FIR. Instead, growers have primarily relied on available equipment and utilized a "trial and error" approach to determine methods that work best with their available equipment. Research into nitrogen (N) fertilization practices and irrigation water management has been ongoing and has progressed to a degree to enable other fundamental research such as seeding and bedding methods to be more successfully undertaken. Therefore, the objective of this study was to compare 4 different seeding and bedding methods in a FIR system.

Procedures

Field studies in 2021 were located at the University of Arkansas System Division of Agriculture's Pine Tree Research Station (PTRS) near Colt, Ark., on a Calloway silt loam soil, and the Northeast Research and Extension Center (NEREC) near Keiser, Ark., on a Sharkey clay soil. At both locations, the RiceTec hybrid RT XP753 was planted at 11 seed/ft^2 for all treatments. Plot sizes were 40 ft wide and 980 ft long at PTRS (2 passes of a 20 ft wide drill) and 30 ft wide and 1200 ft long at NEREC (3 passes of a 10 ft wide drill). For the 3 treatments utilizing drill seeding, drill row spacing was 7.5 inches. For the broadcast treatment, a 10 ft broadcast spreader was used. Treatments included 1) drilling seed into flat soil followed by creating water furrows post-seeding, 2) forming beds/furrows followed by drilling seed into the previously formed beds, 3) drilling seed into flat soil followed by forming beds/furrows post-seeding over the top of seed, and 4) broadcasting seed on the soil surface followed by forming beds post-seeding.

The PTRS location was planted on 24 May and emerged on 2 June. Due to applicator limitations, a single N application of 130 lb N/ac was made on 1 July and irrigation started. It should be noted that current N management recommendations for FIR are to split applications of N depending on various factors. The NEREC location was planted on 25 May and emerged on 4 June. Nitrogen was applied in a 2-way split with 76 lb N/ac applied on 24 June followed by 76 lb N/ac 14 d later. The recommended 30 lb N/ac late boot application was also made on 11 August.

Irrigation events occurred approximately every 3–5 d at PTRS and every 5–7 d at NEREC. At both locations, water was held at the bottom of the field via end blocking to retain irrigation water and increase water use efficiency. At maturity, the field was drained (irrigation ceased) and approximately 2 weeks later the center portion of each plot was harvested and grain moisture content and grain yield were recorded. Yields were calculated as bushels per acre (bu./ac) and adjusted to 12% moisture. A subsample of grain was collected at harvest for milling purposes. The dry rice was milled to obtain percent head rice and percent total white rice (%HR/%TR). The study design was a randomized complete block with 3 or 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 = 0.05).

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Results and Discussion

At the PTRS location in 2021, there was a significant treatment effect for grain yield (Table 1). Broadcasting seed followed by forming beds produced higher grain yields compared to drill flat followed by water furrows and forming beds followed by drilling. However, drilling flat followed by forming beds was similar to the broadcast treatment. No differences were observed in milling yields. At the NEREC location, drilling flat followed by creating water furrows resulted in higher grain yields compared to all other treatments during this study year (Table 2). No differences in milling yields were observed.

It should be noted that these trials were conducted with available equipment at their respective sites, all of which may not have been ideally suited to their use. For instance, a hipper-roller was used at PTRS to form beds (a task to which it is ideally suited) but was manipulated to be able to form water furrows. At NEREC, equipment was generally better suited to each task, with a furrow cleaner (traditionally used in cotton) used to create water furrows, and a bedder used to form beds. Newer styles of bedding and water furrow equipment may provide better results for some treatments and should be evaluated in the future.

Practical Applications

The 2021 FIR seeding and bedding trials provide initial data on optimal planting methods in this new system of rice production. With the current equipment utilized, there are clear differences in the success of FIR. However, work is needed to evaluate newer equipment that may produce different results for some treatments evaluated.

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Literature Cited

Hardke, J.T. 2016. Trends in Arkansas rice production, 2015. *In*: R.J. Norman and K.A.K. Moldenhauer (eds.). B.R. Wells Arkansas Rice Research Studies 2015. University of Arkansas Agricultural Experiment Station Research Series 643:11-21.

Hardke, J.T. 2021. Trends in Arkansas rice production, 2020. *In*: J. Hardke, X. Sha, and N. Bateman (eds.). B.R. Wells Arkansas Rice Research Studies 2020. University of Arkansas Arkansas Agricultural Experiment Station Research Series 676:11-18.

Table 1. Grain yield and milling yield of seeding and bedding methods in furrow-irrigated rice at the University of Arkansas System Division of Agriculture's Pine Tree Research Station during 2021.

Treatment	Grain moisture	Grain yield	Milling Yield
	(%)	(bu./ac)	(%HR/%TR)
Drill flat then furrows	14.2	115.2	43/62
Make beds then drill	14.3	131.3	42/62
Drill then make beds	14.7	147.9	50/64
Broadcast then make beds	13.5	185.5	45/64
$LSD_{(0.05)}$[a]	NS[b]	43.7	NS
P-value	0.6986	0.0224	0.6750/0.9193

[a] LSD = least significant difference.

[b] NS = not significant.

Table 2. Grain yield and milling yield of seeding and bedding methods in furrow-irrigated rice at the University of Arkansas System Division of Agriculture's Northeast Research and Extension Center during 2021.

Treatment	Grain moisture	Grain yield	Milling Yield
	(%)	(bu./ac)	(%HR/%TR)
Drill flat then furrows	22.0	192.4	57/69
Make beds then drill	23.2	175.8	58/69
Drill then make beds	22.3	174.3	58/70
Broadcast then make beds	22.0	167.5	59/69
$LSD_{(0.05)}$ [a]	NS [b]	8.8	NS
P-value	0.5853	0.0004	0.4228/0.6967

[a] LSD = least significant difference.

[b] NS = not significant.

Evaluating Irrigation Timing, Depletion, Water-Use, and Efficiencies in Furrow-Irrigated Rice

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Abstract

A study was conducted to evaluate the performance of 6 different irrigation timings in a furrow-irrigated rice system. 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 were applied to plots as continuously irrigated using the VFTWRS and irrigation every 3, 5, 7, 10, and 14 days. Irrigation events were 24 hours long with a target of 1 ac-in./ac applied during an event. Yield was highest for the continuous irrigation treatment at 201 bu./ac and lowest for the 14-day irrigation treatment at 155 bu./ac. Water use efficiency was the highest in the 14-day treatment at 5.84 bu./in., though not significantly more than the continuous irrigation or the 5-, 7-, or 10-day irrigation timing. Water use efficiency was lowest for continuous irrigation without the use of the VFTWRS at 2.79 bu./in. The results of the study do not suggest that allowable depletions of less than 40% will result in yield penalty.

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 U.S. (Hardke, 2019).

Irrigation is an important input for obtaining maximum yield in furrow-irrigated rice. 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).

Flood irrigation is the most common system of irrigation for rice in Arkansas (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 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 2021. 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 (the 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 irrigated with a novel variable flow tailwater recovery system (VFTWRS) (Kandpal, 2018). End blocking was used to hold a flood at the bottom of the field at a maximum depth of 8 inches. The VFTWRS uses the water held at the bottom of the field and pumps it to the top of the field. Using this system, continuous irrigation was done through recirculation of tailwater. Water was only added to the system when the water at the bottom of the field was depleted. Twelve-inch lay-flat pipe was used for irrigating and hole size was determined using PHAUCET. Flow was measured using McCrometer propeller meters at the hydrant and tailwater pump as well as one inline after the junction of the return pipe and hydrant pipe. The flow meter totalizers were read before and after each irrigation event. Water use efficiency (WUE) was calculated in bu./in. by dividing yield by total irrigation plus total rainfall over the growing season. Rainfall was calculated using a Davis weather station (Davis Instruments, Hayward, Calif.). Rainfall was accumulated from emergence on 21 April until maturity on 9 August. From 5 June to 9 June, 8.52 inches of rainfall was experienced on the field. Much of this rainfall likely

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was not captured by the field and left as runoff; thus the WUE was likely higher than what is reported.

The field was split into 18 plots of approximately 0.9 acres. Each plot contained 12 beds. The study consisted of 3 replications of 6 treatments: continuous irrigation and irrigation every 3, 5, 7, 10, and 14 days. Each irrigation event lasted for 24 hours with a target of 1 ac-in./ac being applied. For the continuous irrigation treatment, water was continuously pumped from 28 June to 17 August using the VFTWRS. Because total water added and total water recirculated was measured, two irrigation totals can be calculated. Water added from the VFTWRS and the hydrant can be added together to give the total as if no tailwater was recovered (labeled "continuous irrigation"), or just water added from the hydrant can be used (labeled "VFTWRS"). For the other treatments, scheduled irrigation started on 28 June and ended on 17 August. The schedule was reset anytime a rain event over 1 inch occurred.

RiceTec 7321 FP was planted on 14 April at a rate of 28 lb/ac. A preemergence application of RoundUp Power Max (40 oz/ac), Command (12.6 oz/ac), and Sharpen (2 oz/ac) was made on 15 April. An application of RiceOne (50 oz/ac), SuperWham (96 oz/ac), and Facet (22 oz/ac) was made on 8 May. On 25 May, an application of RiceStar HT (24oz/ac), Bolero (24 oz/ac), and Preface (6 oz/ac) was made. Preface (6 oz/ac) was applied on 16 June and the last herbicide applied was Basagran (32 oz/ac) and Permit Plus (1 oz/ac) on 25 June. No fungicides or insecticides were applied for the 2021 season. On 6 April, preplant fertilizer was applied by a dry boom spreader at a rate of 0-60-60-10-34 ($N-P_2O_5-K_2O-Zn-SO_4$). Nitrogen (N) was applied through fertigation as liquified urea at a total rate of 125 lb N/ac with 23 lb N/ac applied on 5 June, 46 lb N/ac on 17 June, and 56 lb N/ac on 24 June.

Soil moisture sensor telemetry units (Agsense, Huron, SD) and Time Domain Reflectometer (TDR) sensors (Acclima, Meridan, ID) were used to monitor the soil moisture in each treatment during the season to measure the volumetric water content. The data from the 3- and 14-day sensors were unusable due to equipment failure and irrigation pipe leak that added water to the furrow where these sensors were located, so only the data from the continuous, 5-, 7-, and 10-day sensors is reported. The Water Retention Curve for the Dewitt silt loam soil was made using a HYPROP (Hydraulic Property Analyzer, Water, Meter Group, Pullman, Wash.) and the WP4C, the field capacity was determined to be 35.6% Volumetric Water Content (VWC), the wilting point was determined to be 8.9% VWC, and the available water was determined to be 26.7 % VWC. These numbers were utilized to determine the allowable depletion from the sensor readings.

Results and Discussion

Table 1 shows the yield, water use, and WUE of the different treatments. Yield was highest in the continuously irrigated treatments at 201 bu./ac, though not significantly more than the 3-, 5-, or 7-day treatments at 176, 173, and 169 bu./ac, respectively. Yield was lowest in the 14-day treatment at 155 bu./ac, which is only significantly lower than the continuous treatments. Because each irrigation event applied approximately the same volume of water, the irrigation water use declined as irrigation spacing increased. The continuous irrigation treatment received 55 in. of water, but only 18.9 ac-in./ac was consumptive as the water recirculated by the VFTWRS is deducted. The 3-day irrigation treatment received 19.3 in. The VFTWRS had less water applied than the 3-day treatment while keeping the soil saturated and yielding 25 bu./ac more. The least amount of water was applied to the 10- and 14-day treatments at 9.6 and 9.1 in. All treatments were planted at the same time and the rainfall received by the field was 17.4 in. for all treatments. This brings the continuous irrigation treatment's total water up to 72 in. of total water, and using the VFTWRS, 36.3 in. The 14-day treatment received a total of 26.5 in. of total water.

Across all treatments, excluding the continuous irrigation without the VFTWRS, the WUE was not significantly different. The WUE of the continuous irrigation was the lowest at 2.79 bu./in. and 5.53 bu./in. with tailwater recovery. The 3-day treatment had a WUE at 4.81 bu./in., the lowest of the intermittent irrigation treatments. The WUE increased as irrigation frequency increased with the 10- and 14-day treatments achieving the highest WUE at 5.85 bu./in.

The purpose of irrigation timings is not to determine when irrigation is needed on furrow irrigated rice, but rather to determine at what allowable depletion irrigation is needed so that recommendations can be applied to all soil types using soil moisture sensors. Table 2 shows the volume water content (VWC) and allowable depletion (AD) of the continuous, 5-, 7-, and 10-day treatments. As expected, the VWC decreased and the AD increased as irrigation timing increased. The continuous irrigation stayed in a saturated condition as VWC never was reduced below field capacity after irrigation was first applied, while the 10-day treatment averaged a 67% AD before each irrigation event. The highest AD was observed in all treatments towards the end of the season was 70% for the 10- and 14-day treatments. For the 5-day treatment, field capacity was reached after each irrigation event. For the 7- and 10-day treatments, all but 1 irrigation refilled the profile to field capacity; and for the last 2 irrigations, 1.5 ac-in/ac were applied rather than the prescribed 1 ac-in./ac application because the soils were so dry. While there is a numerical difference of 7 bushels between 3- and 7-day treatments, this suggests a higher allowable depletion may be possible, however, without soil moisture data this is inconclusive. The significant difference between 10- and 14-day treatments, the more frequent irrigation treatments, and the 70% allowable depletion (highest) experienced indicates that depletions this high will result in a yield penalty. A 40% allowable depletion (highest experienced for the 5 day irrigation) is not significantly different in yield from the continuous system and suggests that this allowable depletion is an acceptable level for scheduling sensors in this study. These results support previous findings and recommendations on allowable depletion (Henry et al., 2020), where fewer irrigation treatments were used but recommended an allowable depletion of 40%, however, a less pronounced difference in yield was found. The yield differences found in the 2021 versus the 2020 study are likely due to allowable depletions but are more enhanced because the N rates were different between the years. In 2020, similar irrigation treatments were used with no difference in yield at the 0-7 day treatments but had received 170 lb N/ac as

UAN; whereas in 2021, the irrigation treatments were expanded and yield differences were more pronounced but they only received 125 lb N/ac as liquified urea. The results of the 2 studies suggest that both water and N rates can compensate for yield to some extent when the other is limited. It is also theorized that the continuous irrigation system likely conserves N or reduces water stress and may explain why there was a yield difference of 25 bu./ac in 2021; whereas in 2020, there was only a 5 bu./ac difference between the 0- and 3-day treatments in 2020.

Milling yield was determined from milled samples using a Zaccaria PAZ-1 DTA laboratory rice mill (Zaccaria, Brazil), and results are shown in Table 3. As allowable depletions increased, a lower percentage of total white rice yield (%TR) and a lower percentage of total head rice yield (% HR) were observed. The outliers were the 7-day irrigation treatment, which had the lowest %TR and the 10-day irrigation treatment, which had the highest %HR other than the 0-day treatment.

Practical Applications

Though it did not improve the water use efficiency in 2021, the use of a VFTWRS did record the highest yield relative to the scheduled irrigation treatments. There was a noticeable drop in yield when the soil was allowed to drop below field capacity, but without tailwater recovery in a furrow irrigated system, it is not feasible to irrigate continuously without excessive irrigation water use. This study indicates that the 3-, 5-, and 7-day treatments can achieve acceptable yields without higher water use. A 40% allowable depletion was the highest recorded in the 5-day irrigation treatment and did not result in a significant difference in yield although numerically it was 28 bu./ac less. The study also suggests that when adequate water is provided, such as through a continuous irrigation system, less N may be needed to achieve maximum yield. Conversely, when adequate nitrogen is provided, a higher allowable depletion may be acceptable to maintain yield.

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Literature Cited

Adhya, T. K., B. Linquist, T. Searchinger, R. Wassmann, and X. Yan. 2014. Wetting and drying: reducing greenhouse gas emissions and saving water from rice production. Working Paper, Installment 8 of Creating a Sustainable Food Future. World Resources Institute Washington, D.C.

Arkansas Natural Resource Commission. (2014). Arkansas water plan: Update 2014. http://arkansaswaterplan.org/plan/ArkansasWaterPlan/2014AWPWaterPlan/AWPFinalExecutiveSumm.pdf

Gaspar, J., C.G. Henry, M.W. Duren, A.P. Horton, and H. James. 2016. Effects of three different alternate wetting and drying regimes in rice cultivation on yield, water use, and water use efficiency in a clay soil during a wet year.1 *In*: R.J. Norman and K.A.K. Moldenhauer (eds.) B.R. Wells Arkansas Rice Research Studies 2015. Arkansas Agricultural Experiment Station Research Series 634:251-260.

Hardke, J. and L. Chlapecka. 2020 Highlighted Rice Information Sheets. Arkansas Furrow-Irrigated Rice Handbook. Retrieved from https://www.uaex.uada.edu/farm-ranch/crops-commercial-horticulture/rice/ArkansasFurrowIrrigatedRiceHandbook.pdf

Hardke, J.T. (2019). Trends in Arkansas rice production, 2018. *In*: R.J. Norman and K.A.K. Moldenhauer (eds.) B.R. Wells Arkansas Rice Research Studies 2019. University of Arkansas Agricultural Experiment Station Research Series 667:11-17. Fayetteville.

Henry, C.G., M. Daniels, and J. Hardke. 2013. Water Management. *In*: J.T. Hardke (ed.) Arkansas Rice Production Handbook. University of Arkansas System Division of Agriculture, Cooperative Extension Service. Little Rock, Ark. MP192-2M-11- 13RV.

Henry, C.G., J.P. Pimentel, P.N. Gahr and T. Clark. 2021. Evaluating Irrigation Timing, Depletion, Water-use and Efficiencies in Furrow Irrigated-Rice. *In:* J. Hardke, X. Sha, and N. Bateman (eds.) B.R. Wells Arkansas Rice Research Series 2020. Arkansas Agricultural Experiment Station Research Series Research Series 676:255-258.

Kandpal, V. 2018. Evaluation of a Solar Powered Variable Flow Tail Water Recovery System for Furrow Irrigation. [Masters Thesis, University of Arkansas]. ScholarWorks @ UARK. https://scholarworks.uark.edu/etd/2880/

Singh, S., L. Bhushan, J.K. Ladha, R.K. Gupta, A.N. Rao, and B. Sivaprasad. 2006. Weed management in dry-seeded rice (Oryza sativa) cultivated in the furrow irrigated raised-bed planting system. Crop Protection, 25(5):487-495.

Stephenson IV, D.O., C.E. Wilson Jr, P. Tacker, and S.W. Lancaster. 2008. Determining the potential of furrow-irrigated rice using a 3-and 5-day irrigation schedule in a rice-production system. *In:* R. J. Norman, J.-F. Meullenet and K.A.K. Moldenhauer (eds.) B.R. Wells Rice Research Studies 2007. Arkansas Agricultural Experiment Station Research Series 560:220-227.

Tracy, P. W., B.D. Sims, S.G. Hefner, and J.P. Cairns. 1993. Guidelines for producing rice using furrow irrigation. Extension publications (MU).

USDA-NASS. 2019. United States Department of Agriculture National Agricultural Statistics Service. Crop Production 2019 Summary. Accessed 2 Sept. 2020. Available at: https://downloads.usda.library.cornell. edu/usda-esmis/files/k3569432s/sj139j59z/1257b842j/ cropan20.pdf

Vories, E., P. Counce, and T. Keisling. 2002. Comparison of flooded and furrow irrigated rice on clay. Irrigation Sci. 21(3):139-144.

Table 1. Yield (bu./ac), Irrigation water use (ac-in./ac), and water use efficiency (bu./in.) for varying irrigation treatments.

Treatment	Yield	Water Use	Water Use Efficiency
	(bu./ac)	(ac-in./ac)	(bu./in.)
Continuous (VFTWRS)†	201 a‡	18.9	5.53 a
Continuous	201 ab	54.0	2.79 b
3-Day	176 ab	19.3	4.81 a
5-Day	173 ab	13.9	5.52 a
7-Day	169 ab	12.9	5.58 a
10-Day	158 b	9.60	5.85 a
14-Day	155 b	9.10	5.85 a

† VFTWRS = Variable flow tailwater recovery system.

‡ Means within a column followed by different letters are significantly different at the *P* = 0.05 level. Tukey's honestly significant difference method was used for mean comparison. Rainfall was measured at 17.4 inches.

Table 2. Yield, average % volume water content (VWC) before irrigation, average % volume water content range before irrigation, average allowable depletion (AD) before irrigation, and highest allowable depletion before irrigation for varying irrigation treatments.

Treatment	Yield	% VWC Before Irrigation Event	% VWC Content Range	Average AD before Irrigation	Highest AD just before irrigation
	(bu./ac)	(% AVG)	(%)	(% AVG)	(%)
Continuous	201 a†	41.5	38-43	0	0
5-day	173 ab	29.4	25-37	23	39
7-day	169 ab	21.6	17-31	52	70
10-Day	158 b	17.5	17-18	67	70

† Means within a column followed by different letters are significantly different at the *P* = 0.05 level. Tukey's honestly significant difference method was used for mean comparison.

Table 3. Milling yield by irrigation treatment.

Treatment	%TR†	%HR‡
Continuous	68.5 a§	58.1 a
3-Day	68.4 ab	56.7 abc
5-Day	67.8 ab	55.9 bc
7-Day	66.5 c	56.0 bc
10-Day	67.9 ab	57.5 ab
14-Day	67.2 bc	55.1 c

† Percent total white rice.

‡ Percent total head rice.

§ Means within a column followed by different letters are significantly different at the *P* = 0.05 level.

Evaluating the Interaction of Time Between Irrigations and Rate of Nitrogen Fertilization in Relation to Yield in Rice

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

Abstract

A study was conducted to evaluate the interaction of irrigation timing and nitrogen fertilizer rate in relation to yield. 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. Rice was planted in a no-till furrow-irrigated field on 30-in. bed spacing. Fifty-two small plots, 3 beds wide by 20 ft long were marked inside of 4 different irrigation treatments with 208 plots total. Fertilizer treatments consisted of 7 different rates of nitrogen as N-(n-butyl) thiophosphoric triamide (NBPT) urea and 8 different rates of nitrogen as Environmentally Smart Nitrogen (ESN). The results showed increased yields as both N rates and irrigation frequency increased.

Introduction

The current recommendation for nitrogen (N) in furrow-irrigated rice (FIR) in Arkansas is 138 lb N in four splits or a single pre-flood application of 180 lb N/ac (Hardke and Chlapecka, n.d.). This is based on the irrigation strategy common in Arkansas of irrigating every 3–5 days based on producer preference. In recent years, some research has been done extending the time between irrigations as far as 10 days apart (Henry, 2021). What is unknown is how the N application rates interact with irrigation frequency. Additionally, with the potential for lower yields as the irrigation frequency increases, should N rates be adjusted to account for denitrification and, thus, eventually to regulate yield potential? To provide answers to these questions, a study was developed that would test varying rates of N across different irrigation schedules as a surrogate for soil moisture and allowable depletion.

Procedures

This study was conducted at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center near Stuttgart, Ark. in 2021. The soil in the field is a DeWitt silt loam, which was identified through the USDA Web Soil Survey (Soil Survey Staff, 2017). The field has been in continuous FIR since 2016 and no-till since 2017 (the last year of tillage). Raised beds were constructed on 30-in. spacing using a bedder-roller in 2017, and each subsequent year, a furrow runner (Perkins Sales, Bernie, Mo.) was used to reconstruct a narrow furrow while leaving the beds intact.

The continuous irrigation treatments were irrigated with a novel variable flow tailwater recovery system (VFTWRS) (Kandpal, 2018). End blocking was used to hold a flood at the bottom of the field at a maximum depth of 8 inches. The VFTWRS uses the water held at the bottom of the field and pumps it to the top of the field. Using this system, continuous irrigation can be done through recirculation of tailwater, while water only needs to be added to the system intermittently when the water at the bottom of the field is depleted. Twelve-inch lay-flat pipe was used for irrigating and hole size was determined using PHAUCET.

RiceTec 7321 FP was planted on 14 April at a rate of 28 lb/ac. A preemergence application of RoundUp Power Max (40 oz/ac), Command (12.6 oz/ac), and Sharpen (2 oz/ac) was made on 15 April. An application of RiceOne (50 oz/ac), SuperWham (96 oz/ac), and Facet L (22 oz/ac) was made on 8 May. On 25 May, an application of Rice Star HT (24 oz/ac), Bolero (24 oz/ac), and Preface (6 oz/ac) was made. Preface (6 oz/ac) was applied on 16 June, and the last herbicides applied were Basagram (32 oz/ac) and Permit Plus (1 oz/ac) on 25 June. No fungicide or insecticide was applied for the 2021 season. On 6 April, preplant fertilizer was applied by a dry boom spreader at a rate of 0-60-60-10-34-0 ($N-P_2O_5-K_2O-Zn-SO_4$).

The study consisted of a nitrogen (N) rate study replicated in 4 different irrigation treatments. A replicated complete block design study was established using 7.5 ft by 20 ft plots with 3 replications for N rates. The N rate blocks were then replicated within each irrigation treatment (0/continuous, 5, 10, and 14 days). Small plots were set up to compare the N rate with timing between irrigations. For the irrigation treatments, each plot was 30 feet wide consisting of 12 beds. One was irrigated continuously and one each at 5, 10, and 14 days between irrigations. Nitrogen rates of 60, 80, 100, 120, 140, 160, and 180 lb N/ac as n-butyl thiophosphoric triamide (NBPT) urea were used as well as 40, 60, 80, 100, 120, 140, 160, and 180 lb N/ac as Environmentally Smart Nitrogen (ESN). The urea and ESN plots were separated by a 100-ft buffer, where the randomized block was applied again. Environmentally Smart Nitrogen was applied to the plots on 13 May, and the urea plots were fertilized on 26 May. Fertilizer was

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applied using a 20-in. wide drop spreader. A 0.5-in. rain occurred on 28 May to incorporate the urea.

An irrigation of 1 in. occurred on 18 June. On 26 June, the irrigation treatments were initiated. However, due to complications with fertilizer applications in other parts of the field, irrigation was withheld for this study earlier in the season, and it is likely that the plants experienced water-related stress before 26 June. The irrigation schedule was reset when any rain over 1 in. occurred. The last irrigation was on 17 August. Corresponding allowable depletions (that were the highest experienced) were estimated to be 0 for the continuous irrigation treatment, 39% for the 5-day irrigation treatment, and 70% for the 10-day irrigation treatment. The 14-day irrigation treatment could not be determined because of soil moisture equipment failure but is likely higher or nearly the same as the 10-day treatment.

On 29 August, a Wintersteiger small plot combine was used to harvest a 5-ft wide by 15-ft long strip of each small plot. Samples were milled using a Zaccaria PAZ-1 DTA laboratory rice mill (Zaccaria, Brazil). Influence from the adjacent N reference plot from another study and urea bleed from the upper border area of the field appeared to have bled into some of the N study plots. A heat map was developed and the outer row next to the border area and the row of plots adjacent to the reference plots were removed from the statistical analysis as bleed over urea was suspected from observing the heat map. The ESN fertilizer is less dense than water and has the potential to float if not incorporated. In future studies, ESN should be applied preplant; some movement of ESN could have occurred in the small plot arrangement which could have also skewed the results.

Results and Discussion

The yields for the ESN plots can be seen in Table 1, and the yields for the urea plots are shown in Table 2. The inconsistency in yield may be due to application issues or urea bleed from the border area even though many plots were removed from the heat map analysis. A FIR field presents a unique challenge compared to a flooded rice field in relation to fertilizer application, as beds complicate the drop and ground drive mechanism operation. Because small drop spreaders (<6 ft in width) are generally operated by a small drive wheel, clearance becomes an issue when the wheels do not land on top of the bed. In this study, the clearance issue may have resulted in over or under application when the rate control bar was pulled open when it contacted the ground. To overcome this, other studies have used hand spreading or purpose-built equipment.

However, when the data is plotted and smoothed in Fig. 1 for ESN and Fig. 2 for urea, consistent trends of irrigation treatment and N rate do appear. It should be noted that the trends in Fig. 1 were smoothed to better express the relationship the data suggests between irrigation and N rate, and the authors caution that there is variation in the dataset. It does not appear that a point of diminishing return is clearly identifiable, albeit, for the continuous irrigation treatment and the 5-day treatment, a 140 to 160 lb N/ac rate suggests an optimum rate. It is less clear for the 10- and 14-day irrigation where an optimum N rate and point of yield exists. For ESN, the highest yields were either 140 (continuous and 14-day) or 180 lb N/ac (5- and 10-day). However, with urea, the rates are more consistent, in that the 0-day and 10-day had the highest yield at 160 lb N/ac, and the 5- and 14-day show a peak yield at 140 lb N/ac.

When the data is smoothed and plotted (Figs. 1 and 2), the relationship between irrigation treatment and N rates is clearer than in Tables 1 and 2. A relationship shows that as irrigation frequency increases (lower allowable depletions), so do yields for the same N rate for both ESN and urea.

Rice yields generally showed a trend of increased yield as N rates increased. The study did not find an optimum rate of N for any of the irrigation treatments. The yield of the N plots was considerably lower than the yields of other studies where the irrigation treatment was the same, indicating that N rates may be less than reported or that the water stress experienced earlier in the season before irrigation was applied reduced yields. However, the trend of N rate with respect to irrigation frequency shows well in Figs. 1 and 2 for ESN and urea. No significant difference was found in head rice yield or total white rice yield between N rates.

Practical Applications

Few small plot studies exist that evaluate the N rate in FIR and none could be found that reported the interaction of irrigation timing (which corresponds to soil moisture and allowable depletion) and N rate. This preliminary study suggests that there may be an interaction between N rate and irrigation frequency, or more importantly soil moisture and allowable depletion. Future work in this area may help explain yield penalties that are commonly associated with FIR and such work may be useful in developing recommendations that account for both irrigation and nitrogen management.

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Literature Cited

Hardke, J. and J. Chlapecka (eds). Arkansas Furrow-Irrigated Rice Handbook. University of Arkansas System Division of Agriculture, Little Rock, Ark.

Hardke, J. and J. Chlapecka. 2020 Highlighted Rice Information Sheets. Arkansas Furrow-Irrigated Rice Handbook. Available at: https://www.uaex.uada.edu/farm-ranch/crops-commercial-horticulture/rice/ArkansasFurrowIrrigatedRice-Handbook.pdf

Henry, C.G., J. Pimentel, P. Gahr, and T. Clark. 2020. Evaluating Irrigation Timing, Depletion, Water-Use, and Efficiencies in Furrow Irrigated-Rice. *In*: Hardke, J., X. Sha, and N. Bateman (eds.). B.R. Wells Arkansas Rice Research Studies

2020. Arkansas Agricultural Experiment Station Research Series 676: 255-258. Fayetteville.
Kandpal, V. 2018. Evaluation of a Solar Powered Variable Flow Tail Water Recovery System for Furrow Irrigation. [Masters Thesis, University of Arkansas]. ScholarWorks@UARK. https://scholarworks.uark.edu/etd/2880/
Soil Survey Staff, Natural Resources Conservation Service, United States Department of Agriculture. Web Soil Survey. Accessed 1 March 2017. Available at: http://websoilsurvey.sc.egov.usda.gov/

Table 1. Rate of nitrogen as Environmentally Smart Nitrogen within 4 irrigation treatments and the effect on yield.

	Irrigation Timing			
Nitrogen Rate	Continuous	Every 5 Day	Every 10 Day	Every 14 Day
(lb N/ac)	(bu./ac)	(bu./ac)	(bu./ac)	(bu./ac)
40	124	87	84	73
60	132	108	98	83
80	127	120	109	96
100	148	112	107	91
120	151	110	110	104
140	**159**[a]	116	105	**108**
160	153	122	117	98
180	158	**149**	**127**	105

[a] Numbers in bold are the highest yields.

Table 2. Rate of nitrogen as urea within 4 irrigation treatments and the effect on yield.

	Irrigation Timing			
Nitrogen Rate	Continuous	Every 5 Day	Every 10 Day	Every 14 Day
(lb N/ac)	(bu./ac)	(bu./ac)	(bu./ac)	(bu./ac)
60	142	102	85	58
80	123	122	101	93
100	147	133	105	104
120	143	125	116	110
140	159	**143**	108	**119**
160	**170**[a]	140	**132**	93
180	160	126	116	107

[a] Numbers in bold are the highest yields.

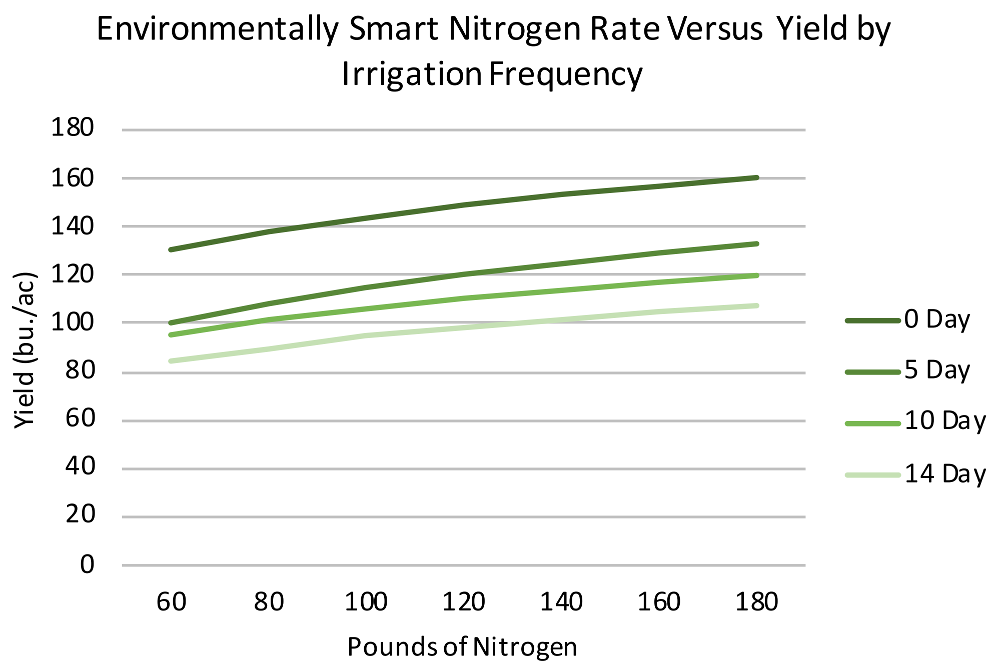

Fig. 1. Environmentally Smart Nitrogen rate versus yield by irrigation frequency.

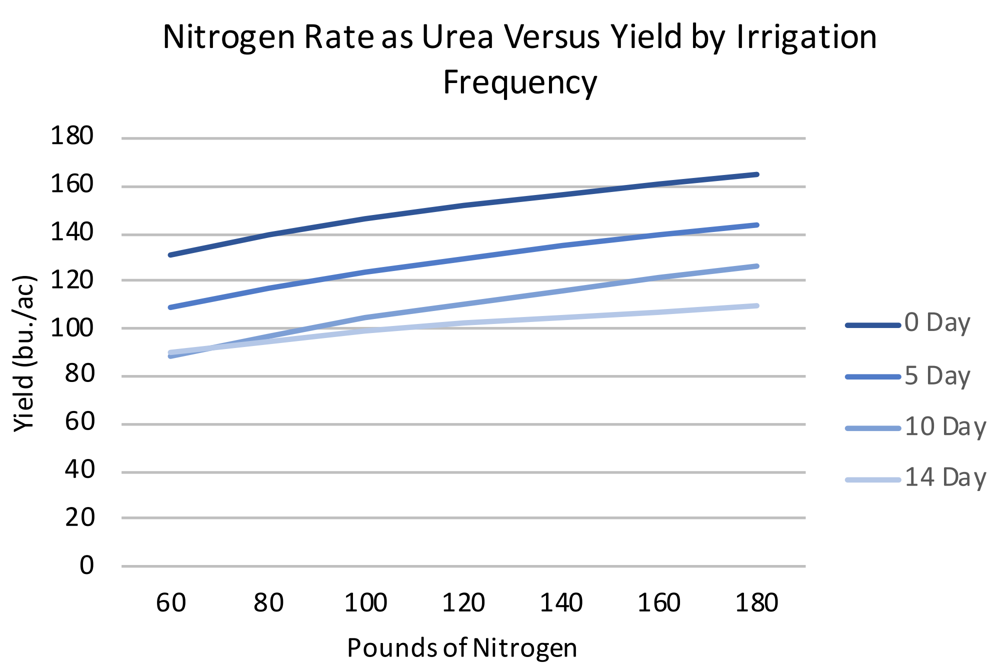

Fig. 2. Urea rate versus yield by irrigation frequency.

Evaluating the Potential of Fertigating Row Rice with Dissolved Urea in Arkansas

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

Abstract

A study was conducted to evaluate the potential of applying nitrogen (N) 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, Arkansas. The study field is 40 acres that has been no-till since 2018 and was planted to RiceTec 7321 FP on 30-in. beds. Except for N, all fertilizers were applied as pelletized fertilizers. Nitrogen was applied over 3 events with the irrigation water through a specially designed fertigation valve for surface irrigation. The N source was uncoated urea that was dissolved in water at a rate of 7.5 lb urea/gal water. A yield of 201 bu./ac was achieved using 124 lb N/ac.

Introduction

Current nitrogen (N) fertilizer recommendations for furrow-irrigated rice (FIR) in Arkansas on a silt loam is a 3-way split with a total of 120 lb/ac. The first application should be before irrigation begins but the next 2 spaced 7–10 days apart would be post-irrigation initiation, preventing the use of ground equipment for application (Hardke, 2021). In a study of N rates in FIR on clayey soils, Chlapecka et al. (2021) found that splitting the N over 3 applications resulted in the highest yield, but the N rate exceeded that recommended for flooded rice. A single application was able to achieve the same yield but required a greater rate of nitrogen (180 lb N/ac). This is most likely due to the higher volatilization of N in the aerobic soil condition present in a furrow-irrigated field.

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. (2014) in Bangladesh found that a lower rate of nitrogen in a furrow irrigated rice field using fertigation yielded greater than a conventional flood irrigated field. With the potential benefits of fertigation, this study was conducted to assess the feasibility of using fertigation to apply N in a FIR field in Arkansas.

Procedures

This study was conducted at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center near Stuttgart, Ark. in 2021. The soil in the field is predominately a DeWitt silt loam, which was identified through the USDA Web Soil Survey (Soil Survey Staff, 2017). The field has been in continuous FIR since 2016 and no-till since 2017 (the last year of tillage). Raised beds were constructed on 30-in. spacing using a bedder-roller in 2017 and each subsequent year, a furrow runner (Perkins Sales, Bernie, Mo.) has been used to reconstruct a narrow furrow while leaving the beds intact. Treatments were replicated 3 times, plots were 30 ft in width and 1300 ft long.

The field was irrigated with a novel variable flow tailwater recovery system (VFTWRS) (Kandpal, 2018). End blocking was used to hold a flood at the bottom of the field at a maximum depth of 8 in. The VFTWRS uses the water held at the bottom of the field and pumps it to the top of the field. Using this system, continuous irrigation can be done through recirculation of tailwater while water only needs to be added to the system intermittently when the water at the bottom of the field is depleted. Six different irrigation timings were being studied: continuous irrigation and irrigation every 3, 5, 7, 10, and 14 days. Twelve-inch lay flat pipe was used for irrigating and hole size was determined using PHAUCET.

On 6 April, preplant fertilizer was applied by a dry boom spreader at a rate of 0-50-10-34-0 (N-P_2O_5-K_2O-Zn-SO_4). RiceTec 7321 FP was planted on 14 April at a rate of 28 lb/ac. A preemergent application of RoundUp Power Max (40 oz/ac), Command (12.6 oz/ac), and Sharpen (2 oz/ac) was made on 15 April. An application of RiceOne (50 oz/ac), SuperWham (96 oz/ac), and Facet (22 oz/ac) was made on 8 May. On 25 May, an application of RiceStar HT (24 oz/ac), Bolero (24 oz/ac), and Preface (6 oz/ac) was made. Preface (6 oz/ac) was applied on 16 June and the last herbicides applied were Basagram (32 oz/ac) and Permit Plus (1 oz/ac) on 25 June. No fungicide or insecticide was applied for the 2021 season.

Nitrogen was applied as urea dissolved in water over 3 applications through the irrigation water. Application 1 was on 5 June and applied at 23 lb N/ac, application 2 was on 17 June and applied at 46 lb N/ac, and application 3 was on 24 June and applied at 56 lb N/ac for a total of 125 lb N/ac. A fertigation injector system was installed after the universal hydrant. On the upstream side of the injection port, a one-way valve prevented the flow of N solution back into the irrigation system. An Inject-O-Meter fertigation injector with the capability of 20–200 gph was used to pump the solution into the irrigation water. Irrigation was initiated and 1 hour was allowed to elapse before the urea solution was injected into the irrigation system. Fertigation pump rates were used that would deplete the solution when the irrigation wetting front fully advanced through the field. The typical advance time for this field has been 10 hours.

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Little information is available regarding the solubility of urea in water. May (2022) reported making urea-water solutions. The reaction of urea and water is endothermic and the solubility of urea decreases as temperature decreases (May, 2017). A 37% urea by weight mixture, 17% N, was used for the first application. This consisted of 1550 lb of uncoated urea added to 320 gallons of water in 2–265-gallon shuttle tanks. Theoretically, a starting water temperature of 90 °F would be able to dissolve that quantity of urea without any extra heat. The water used to fertigate was initially at only 65 °F, and the water was allowed to warm using ambient air temperature. Two major issues were encountered. First, without agitation, the higher density solution fell to the bottom where the undissolved fertilizer was prevented from further dissolution. The tanks were fitted with special fittings to allow a fertigation pump to pull water from the top of the tank and inject it at the bottom in order to stir the solution. The second issue was the rate of energy transfer from the air to the water. Though it would have been possible to wait long enough for the tank to be heated for the ambient air temperature, an 1800 W stock tank heater was used to speed up the process.

For the second and third applications, a 48% urea by weight mixture, 22% N, was used. Three 265-gallon shuttle tanks were used. The aforementioned Urea Solubility Production fact sheet states that to offset the cooling effect of urea dissolving into water, 110 BTU/lb of urea is required (May, 2017). Using two 1800W stock tank heaters and a total of 3800 lb of urea, a time of 11 hours was needed to heat the solution enough for complete urea dissolution. In practice, the solution could be reacted the day before the fertigation event and left overnight resulting in a completely dissolved solution the next morning.

A 30-ft reference plot was placed on the same field adjacent to the fertigation plots. On this plot, all fertilizer was applied as coated urea at a rate of 300 lb N/ac on 26 May. Four 30-ft plots with 170 lb N/ac as coated urea were fertilized on 26 May as well. None of these plots received any irrigation during the fertigation of the fertigation plots. The 300 lb N/ac plot was irrigated continuously after 26 June while the 170 lb N/ac treatment had one continuously irrigated plot and 1 each at 5-, 10-, and 14-day irrigation spacing. Other than irrigation and N fertilizer, these plots were managed identically to the fertigation plots. The 170 and 300 lb N/ac strips were not replicated but give a rough estimate to compare with the fertigation treatment. Tissue samples were taken from the top, middle, and bottom of the reference and fertigation plots and sent to the Agriculture Research Laboratory in Fayetteville, Ark. Samples were averaged across the top, middle, and bottom for Fig. 1. Samples were taken weekly from 14 June until 19 July. Normalized Difference Vegetation Index (NDVI) measurements were taken on 12 July for the reference and fertigated plots, using the procedure specified in the Rice Production Handbook (CES, 2018).

Results and Discussion

Uniformity of application ended up being the greatest challenge. With the field being no-till since 2018, some of the beds, mostly on the top of the field, were severely eroded or compacted from wet field conditions at harvest in 2020. In fact, in some parts of the field, furrows and beds were no longer recognizable. This resulted in a large discrepancy in the advance time of individual furrows. For fertigation, this discrepancy resulted in significant and very visible differences in N and irrigation water delivery. Early in the season, many furrows did not receive any N or irrigation water from the first and second N applications.

Many attempts at correction ensued. Shoveling the top of the dry furrows did allow water to move down them but it is a very labor-intensive solution. Even after initial corrections, several furrows still exhibited N-deficient plants. Another corrective action was used to assist with dry and nutrient furrow deficiencies; first small tubing and drip irrigation mainline connectors were used to deliver irrigation water about 25 feet away from the crown pipe. This was far enough away that the water then advanced along the furrow. Another mitigation strategy was to plug holes of over-fertilized furrows and only deliver the last fertigation to visually N-deficient furrows.

A visual increase in furrows that did not receive N at the bottom of the field could be seen. Comparing the yields, the plots with little shoveling yielded 198 bu./ac, just 3 bu./ac less than the fertigation study plots which received much more attention.

While the mitigation strategies helped, it was observed that as the rice developed during the vegetative stage, the vegetative retardance also increased and the break-over between furrows shifted to the path of least resistance; thus, as furrows with smaller plants and less retardance, were a more likely path for water flow during the last fertigation. It is believed that this is the reason that the nutrient deficiencies observed earlier in the season disappeared later in the season.

The results of the tissue samples are shown in Fig. 1 between the continuous irrigation treatment and the reference N plot (these plots that were sampled are shown in Fig. 2 also). Sufficiency levels are shown and the tissue N concentration is generally around 0.5–1% less than the reference plot, suggesting that during the season the fertigated plots were short of N. Around 4 July, the tissue samples drop well below the book value sufficiency levels. An additional application of N would likely have brought up tissue concentrations (and improved yield) if applied around this time, or up until the last day for boot N around 10 July.

For the NDVI measurements, the reference plot averaged 0.84, 0.83, and 0.84 for the top, middle, and bottom of the field, respectively. The fertigated plots averaged 0.80, 0.78, and 0.75 for the top, middle, and bottom of the field, respectively. The data did not indicate a 50% or greater chance of a mid-season N application being beneficial according to current Extension recommendations.

The yield of the fertigation plots was 201 bu./ac using 125 lb N/ac. The reference plot with 300 lb N/ac yielded 214 bu./ac, and the plot with 170 lb N/ac as pelletized urea yielded 221 bu./ac. As can be seen in Fig. 2, the color and height of the rice are very distinct and the difference in foliage was observed to be very different. These two plot comparisons are not replicated, but are large, single, adjacent plots. It is interesting that the reference plot (300 lb N/ac) was less than the urea plot (170 lb N/ac) and the issues encountered with the distribution of fertilizer likely played a role. It is difficult to draw a firm conclusion because of the many different factors. However, a very high yield was achieved on a very modest application rate of N with the added complication of distribution uniformity issues, suggesting that even in the most challenging conditions, very high yields and good results are obtainable in FIR. Additionally, Chlapecka et al. (2021) found a reduction in yield in furrow-irrigated rice if enough N was not applied during tillering, and this could have been a contributing factor for the rice given that N for the entire field was applied differently based on how well the furrow advanced. For the 170 lb N/ac as pelletized urea and the reference strip, all N was applied at the 4- to 6-leaf stage. The first N application in the fertigated plots was delayed and was only 18% of the total applied N in the fertigation treatments.

Practical Applications

The use of liquified urea was demonstrated to be feasible though potential issues were encountered. Though an economic analysis was not conducted, generally uncoated urea is less expensive per unit of N than UAN. The drawback is that dissolving urea into water requires specialized equipment and effort. Another drawback is that liquified urea has a concentration of 22% N compared to UAN, which has a concentration of 32% N. This means a larger volume of solution must be handled. One potential benefit is that the availability of UAN can be limited in some areas while acquiring uncoated urea may be more available.

The potential or practicality of fertigation in FIR remains unknown. Furrow irrigated rice has been shown to yield the same as conventionally fertilized furrow irrigated rice. The use of fertigation makes it possible to apply N and other micronutrients when the field conditions are too wet for a ground rig application and aerial application. The potential for reduced volatilization and delivering N closer to when it is needed by the rice plant is still an area of research that shows promise.

The study also suggests that even with a modest application of 125 lb N/ac, nearly optimum yields are achievable when a continuous irrigation system is used in a FIR system.

Acknowledgments

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Literature Cited

Bhuyan, H.M., R. Ferdousi, and T. Iqbal. 2014. Increasing Yield and Agronomic Efficiency of Boro Rice (*Oryza sativa*) by Fertigation with Bed Planting Compared with Conventional Planting. Int. J. Agric. Biol. Eng. 7:34-47. https://dx.doi.org/10.3965/j.ijabe.20140705.004

CES. 2018. In: J.T. Hardke (ed). Arkansas Rice Production Handbook. University of Arkansas System Division of Agriculture's Arkansas Cooperative Extension Service, MP 192, Little Rock, Ark.

Chlapecka, J.L., J.T. Hardke, T.L. Roberts, and E.E. Gbur. 2021. Nitrogen Management of Furrow-Irrigated rice on Clayey Soils. Agron. J. 113:3159-3168. https://dx.doi.org/10.1002/agj2.20714

Gaspar, J., C.G. Henry, M.W. Duren, A.P. Horton, and H. James. 2016. Effects of three different alternate wetting and drying regimes in rice cultivation on yield, water use, and water use efficiency in a clay soil during a wet year. *In*: R.J. Norman and K.A.K. Moldenhauer (eds.) B.R. Wells Arkansas Rice Research Studies 2015. Arkansas Agricultural Experiment Station Research Series 634:251- 260. Fayetteville.

Hardke, J. and L. Chlapecka. 2020 Highlighted Rice Information Sheets. Arkansas Furrow-Irrigated Rice Handbook. Available at: https://www.uaex.uada.edu/farm-ranch/crops-commercial-horticulture/rice/ArkansasFurrowIrrigatedRice-Handbook.pdf

Hardke, J.T. (2019). Trends in Arkansas rice production, 2018. *In*: R.J. Norman and K.A.K. Moldenhauer (eds.) B.R. Wells Arkansas Rice Research Studies 2019. University of Arkansas Agricultural Experiment Station Research Series 667:11-17. Fayetteville.

Henry, C.G., M. Daniels, and J. Hardke. 2013. Water Management. *In*: J.T. Hardke (ed.) Arkansas Rice Production Handbook. University of Arkansas System Division of Agriculture, Cooperative Extension Service. Little Rock, Ark. MP192-2M-11-13RV.

Kandpal, V. 2018. Evaluation of a Solar Powered Variable Flow Tail Water Recovery System for Furrow Irrigation. [Masters Thesis, University of Arkansas]. ScholarWorks@UARK. https://scholarworks.uark.edu/etd/2880/

May, Jim. Jim May Solubilizing Urea 2017 [PowerPoint Slides]. Fluid Fertilizer Foundation. Accessed 25 February 2022. Available at: https://fluidfertilizer.org/wp-content/uploads/2017/12/Jim-May-Solubilizing-Urea-2017.pdf

Singh, S., L. Bhushan, J.K. Ladha, R.K. Gupta, A.N. Rao, and B. Sivaprasad. 2006. Weed management in dry-seeded rice (*Oryza sativa*) cultivated in the furrow irrigated raised-bed planting system. Crop Protection, 25(5):487-495.

Stephenson IV, D.O., C.E. Wilson Jr., P. Tacker, and S.W. Lancaster. 2008. Determining the potential of furrow-irrigated rice using a 3-and 5-day irrigation schedule in a rice-production system. *In*: R.J. Norman, J.-F. Meullenet, and K.A.K. Moldenhauer (eds.). B.R. Wells Rice Research Studies 2007. Arkansas Agricultural Experiment Station Research Series 560:220-227. Fayetteville.

Tracy, P. W., B.D. Sims, S.G. Hefner, and J.P. Cairns. 1993. Guidelines for producing rice using furrow irrigation. Extension publications (MU).

Soil Survey Staff, Natural Resources Conservation Service, United States Department of Agriculture. Web Soil Survey. Accessed 1 March 2017. Available at: http://websoilsurvey.sc.egov.usda.gov/

USDA-NASS. 2019. United States Department of Agriculture National Agricultural Statistics Service. Accessed 2 Sept. 2020. Available at: https://downloads.usda.library.cornell.edu/usda-esmis/files/k3569432s/sj139j59z/1257b842j/cropan20.pdf

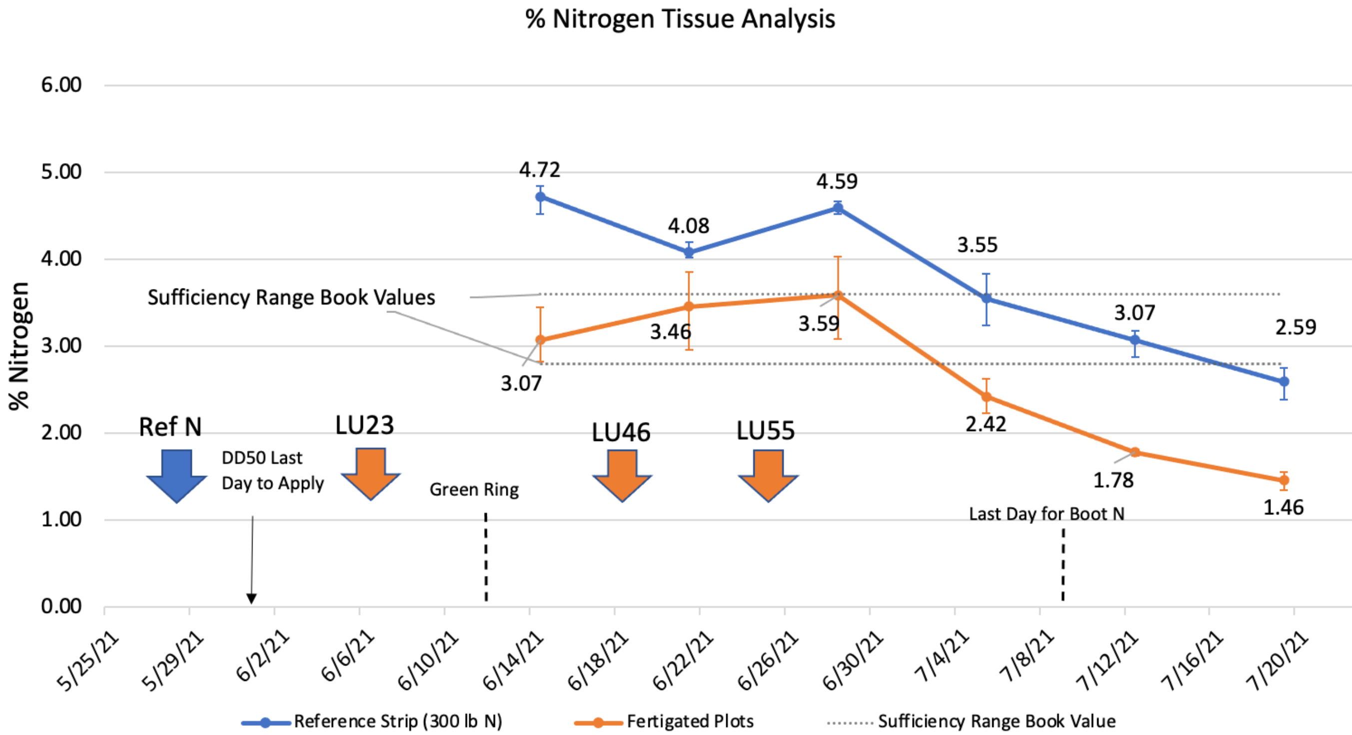

Fig. 1. Tissue analysis over time of reference N plot (300 lb N/ac) and fertigated plots (125 lb N/ac).

Fig. 2. Picture taken on 22 June 2021 at the bottom of the field looking towards the top of the field. On the left is a continuous irrigation plot, 204 bu./ac with 125 lb N/ac of liquified urea applied. On the right is an N reference plot, 214 bu./ac with 300 lb N/ac (half pelletized urea and half fertigated urea).

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

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Abstract

The University of Arkansas System Division of Agriculture's Irrigation Yield Contest was conducted in 2018, 2019, 2020, and 2021. The contest was designed to promote better use of irrigation water as well as to record data on water use and water use efficiency for various crops. Unlike yield contests, where winners are decided by yield alone, the irrigation contest results are decided by the highest calculated total water use efficiency (WUE) achieved by a producer. The contest consists of 3 categories: corn, rice, and soybeans. All fields entered were required to show a history of irrigation and production on the field. Irrigation water was recorded by using 6-, 8-, 10-, and 12-in. portable mechanical flow meters. Rainfall totals were calculated using Farmlogs™. The contest average WUE measured in the contest between 2018–2021 for rice was 4.88 bu./in. The winning WUE was 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. Rice contest participants report using on average 26.8 ac-in./ac of irrigation water and 72% are using the furrow irrigation production system in 2020 and 2021. Additionally in 2021, 3 growers used a novel pit-less tailwater system developed by the University of Arkansas System Division of Agriculture.

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 level 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 1 using the IWM tools and 1 using conventional irrigation methods. It was found that the implementation of all 3 IWM tools reduced water use in the soybean fields by 21% while not reducing yields. This resulted in an increase in a water use efficiency (WUE) of 36%. For the cornfields, a 40% reduction in water use was observed and WUE went up by 51%. For both soybeans, when the cost of the new IWM tools was incorporated, 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

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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. To find the predicted drain date for the rice field, the University of Arkansas System Division of Agriculture DD50 Rice Management Program was used (Hardke et al., 2020). Rainfall is adjusted for extreme events.

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 4 years that the competition has been conducted, there have been 51 fields entered for rice. The average WUE over the 4 years was 4.88 bu./in. By year, the average WUE was 5.46 bu./in. for 2021 with 10 contestants, 4.69 bu./in. for 2020 with 21 contestants, 5.16 bu./in. for 2019 with 8 contestants, and 5.17 bu./in. for 2018 with 12 contestants (Table 1). 2018 and 2019 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 than in 2018, 2019, and 2020. The highest (winning) WUE for each year was 9.77 bu./in. in 2021, 8.72 bu./in. for 2020, 7.24 bu./in. for 2019, and 7.80 bu./in. for 2018.

It is a common belief that a higher or lower yield will help obtain a better WUE. By plotting WUE on 1 axis and yield on the other, a best fit line can be calculated. The line calculated has a coefficient of determination of $R^2 = 0.193$ where $R^2 > 0.95$ shows no relationship or correlation exists. There is no discernable relationship between yield and WUE in rice. Another commonly held belief by contestants is that a higher amount of rainfall will help to increase WUE. By plotting rainfall against WUE, linear regression was used to determine if there was a linear relationship. The coefficient of determination was determined to be $R^2 = 0.01$. There is no discernable relationship between WUE and precipitation. The lack of relationships suggests that neither precipitation nor yield is a factor in achieving high WUE and achieving high WUE is due to irrigation management.

In 2015 a survey was conducted across the Mid-South to determine the adoption rate of various irrigation water management (IWM) tools (Henry 2019). On the entry form for the contest, a similar survey was included to assess the usage of IWM tools among the participants in the contest to the average in use in the Mid-South and in Arkansas. In the 2015 survey, 40% reported using 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 the participants across all 3 categories included responses in their entry form. The IWM tool that was most widely adopted was CHS. The average use among respondents was 89% across all 3 years with 88% in 2018, 72% in 2019, 100% in 2020, and 97.5% in 2021. The use of furrow irrigated rice saw an increase in respondents from 56% and 50% in 2018 and 2019, respectively, to 73% in 2020, and 80% in 2021. Adding all years together, 62% of rice contest fields used furrow irrigation. Another water-saving method of rice irrigation is multiple inlet rice irrigation (MIRI). Twenty-one percent of respondents from all 4 years reported using MIRI with 33% in 2018, 17% in 2019, and 27% in 2020. In 2021, 5 respondents reported from 75% to 100% adoption of MIRI. Fifty-four percent of respondents from all 4 years said that they used soil moisture sensors on their farm, with 60% in 2018, 67% in 2019, 42% in 2020, and 50% in 2021. Surge valves were the least used IWM tool, with a 4 year average use rate of 28%. Those that reported using surge irrigation over the 4 years of the contest were 44% in 2018, 28% in 2019, 16% in 2020, and 25% in 2021.

The winner of the 2021 contest used a novel pit-less tailwater pump system developed by Henry et al. (2019) in a furrow irrigated rice field. This was the first time in the four-year history that a furrow irrigated rice field placed first place in the contest.

Practical Applications

Irrigation water use efficiency (WUE) of working farms is not a common metric available in the literature, and it is not a metric familiar to rice farmers. The data recorded from the Arkansas Irrigation Yield Contest provides direct feedback to irrigators about their irrigation performance in maintaining high yields and low irrigation water used. Such direct feedback to Arkansas rice farmers will likely provide many with a competitive advantage when water resources become more scarce. It 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 4 years averaged 199 bu./ac, 28.7 ac-in./ac of irrigation, and a total water use of 44.3 in.

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Literature Cited

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

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

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

Hardke, J.T. 2020. University of Arkansas DD50 Rice Management Program. Accessed 7 January 2021. http://dd50.uada.edu

Hardke, J.T. 2019. Trends in Arkansas rice production, 2018. *In*: R.J. Norman and K.A.K. Moldenhauer (eds.) B.R. Wells Arkansas Rice Research Studies 2019. University of Arkansas Agricultural Experiment Station Research Series 667:11-17. Fayetteville.

Henry, C.G., B. Kohler, and J. Nichols. 2019. Irrigation system. U.S. Patent Number 20190307083A1. Filed December 15, 2017, Pending October 10, 2019.

Henry, C.G., M. Daniels, and J. Hardke. 2013. Water Management. *In*: J.T. Hardke (ed.) Arkansas Rice Production Handbook. University of Arkansas System Division of Agriculture, Cooperative Extension Service. Little Rock, Ark. MP192-2M-11-13RV.

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

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

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

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

Spencer, G.D., L.J. Krutz, L.L. Falconer, W.B. Henry, C.G. Henry, E.J. Larson, H.C. Pringle III, C.J. Bryant, and R.L. Atwill. 2019. Irrigation water management technologies for furrow-irrigated corn that decrease water use and improve yield and on-farm profitability. Crop Forage Turfgrass Mgmt. 5(1) 180100:1-8. https://dx.doi.org/10.2134/cftm2018.12.0100

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

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

Vories, E., P. Counce, and T. Keisling. 2002. Comparison of flooded and furrow irrigated rice on clay. Irrigation Science, 21(3):139-144. https://dx.doi.org/10.1007/s00271-002-0056-0

Table 1. Maximum, average, and minimum for 2018, 2019, 2020, and 2021 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.)
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	250	18.1	92.1	104.2
	Average	4.69	196.4	14.9	32.4	47.4
	Minimum	1.55	120.0	11.7	14.0	27.6
2019	**Maximum**	7.24	209.9	27.1	30.5	48.7
	Average	5.20	189.6	19.2	19.9	39.2
	Minimum	3.55	162.8	14.9	13.4	28.7
2018	**Maximum**	7.80	266.6	16.0	47.9	63.8
	Average	5.20	208.9	13.7	28.1	42.5
	Minimum	2.84	131.9	7.4	16.0	29.4
4 Yr.	**Average**	4.92	199.0	15.4	28.7	44.3

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 trials where various K rates (0, 40, 80, 120, and 160 lb K_2O/ac) have been applied annually for several years. Whole, aboveground plant samples were collected at 50% heading in 2020 and Y-leaf samples were collected at the booting growth stage in 2021. With Very Low (<61 ppm) Mehlich-3 K in the control plots, both cultivars responded to K fertilization in 2020 and 2021. Without K fertilization, the pure-line (Diamond) produced 75% and 69% of the maximum yield produced when fertilized with K, while the hybrids produced 64% (RT 7521 FP) and 39% (RT 7321 FP) of maximum yields. For Diamond, the relationship between yield and tissue-K concentration was consistent with critical concentrations suggested by previous research. Grain yields of the hybrid cultivars, however, were lower than expected based on tissue-K concentrations and may indicate a difference in the responsiveness of hybrid and pure-line cultivars to K fertilization. Results of this study suggest that the two hybrids (RT 7521 FP and RT 7321 FP) may be more responsive to K fertilizer than pure-line cultivars, but recent trials have shown another hybrid (RT Gemini 214 CL) to be less responsive than pure-line cultivars. 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. Based on soil samples submitted to the University of Arkansas System Division of Agriculture's Soil Testing Laboratory in Marianna in 2019, DeLong et al. (2021) reported that 32% of sampled acreage following soybean [*Glycine max* (L.) Merr.] or rice, which accounted for the majority of Arkansas rice produced in 2020 (68% followed soybean and 24% followed rice; Hardke, 2021), 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 and that appropriate K fertilization of K-deficient rice resulted in yield increases of 6 to 51 bu./ac (up to 48% increase relative to control). These features highlight the benefit 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 regular nutrient management of U.S. mid-South rice production systems. Recent research (Gruener et al., 2019) 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 the tissue-K concentration of whole-plant samples collected at R1 or R3, so data is limited for interpretation of K nutritional status in the 4 to 5 weeks between 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., 2019; 2020), but most previous research in Arkansas has been focused on the response of pure-line rice to K fertilization. Dobermann and Fairhurst (2000)

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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. (2019, 2020), however, observed a positive yield response to fertilizer-K in 3 of 5 site-years for pure-line rice, while hybrid rice responded positively in only 2 of the 5 matching site-years, with average yield increases of 28 and 14 bu./ac for the pure-line and hybrid cultivars, respectively, in the responsive sites. 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 (1 trial is rice and the other is soybean each year). Rice main plots were 16-ft long and 25-ft wide in 2020 on the trial area established in 2000 and 26-ft wide in 2021 on the area established in 2002, 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 subplots by seeding 2 drill passes with a pure-line (Diamond) and 2 passes with a hybrid cultivar (RT 7521 FP in 2020 and RT 7321 FP in 2021). The seeding rates used in the study were 65 lb seed/ac and 25 lb seed/ac for the pure-line and hybrid cultivars each season, respectively. The trials contained 8 replicates in 2020 and 9 replicates in 2021, each consisting of K-fertilization rates of 0, 40, 80, 120, and 160 lb K_2O/ac. Fertilizer-K treatments were applied on 1 May 2020 (3 days prior to planting) and 28 April 2021 (prior to planting on the same day). A uniform application of triple superphosphate (60 lb P_2O_5/ac) was broadcast over all plots at the same time as the K-treatment application and a uniform application of urea treated with NBPT (130 lb N/ac) was made in each trial prior to flooding at the 5-leaf stage to ensure adequate P and N availability for rice growth. A flood was established 1 day after preflood-N application in 2020 and 3 days after application in 2021 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.

In 2020, whole, aboveground rice plants were collected from the 0, 80, and 160 lb K_2O/ac treatments at heading from a 3-ft section of an inside row that would not be harvested. In 2021, 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, weights were recorded for whole-plant samples, and tissue was ground to pass a 1-mm sieve prior to digestion by nitric acid and analysis by inductively coupled plasma atomic emission spectroscopy.

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 the 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

As expected, after about 20 years of annual fertilizer-K rate applications, Mehlich-3 extractable soil K in 2020 and 2021 was closely related to K application rate with soil-test K increasing as fertilizer-K application rate increased (Table 1). Similarly, tissue-K concentration and K uptake from whole, aboveground rice plants sampled at 50% heading in 2020 were affected by K rate, ranging from 0.77 to 1.89% K and from 52 to 183 lb K/ac (Table 2). Rice cultivar did not significantly influence tissue-K concentration, total aboveground K uptake, or grain yield in 2020. Averaged between the cultivars, grain yield was lowest (124 bu./ac) when no fertilizer-K was applied and greatest with application rates of 120 and 160 lb K_2O/ac, which did not differ from each other and averaged 177 bu./ac. Grain yields from the application of 40 or 80 lb K_2O/ac were similar to each other but significantly greater than the control and less than yields from higher application rates. These results are consistent with a 2011 study, where Slaton et al. (2012) reported a yield loss when aboveground, whole-plant tissue-K at heading was 1.14% or less, while concentrations of 1.46% and above produced near-maximum yields. The tissue-K concentration of the intermediate K rate treatment in 2020 (1.33%) indicates that the rice should have sufficient K (>95% relative yield), based on the 1.3% critical concentration suggested by Slaton et al. (2009). The positive yield response, averaged between cultivars, observed in 2020 with tissue-K at 1.33%, may be the result of varying responsiveness of pure-line and hybrid rice to fertilizer K, as Slaton et al. (2009) predominantly examined pure-line rice. Looking only at the pure-line rice in 2020, the 80 lb K_2O/ac rate resulted in 1.30% tissue-K and achieved 97% relative yield, while the hybrid had 1.35% tissue K and produced a relative yield of 89%.

Grain yields in 2021 were influenced by the interaction of fertilizer-K rate and rice cultivar (Table 3). The greatest yield, numerically, was 162 bu./ac from Diamond when 120 lb K_2O/ac was applied, but that did not differ significantly from yields of Diamond at 80 or 160 or RT 7321 FP at 120 or 160 lb K_2O/ac rates. Overall, grain yields of both cultivars were lower in 2021 than in 2020, but particularly for the hybrid (RT 7321 FP) due to substantial lodging, which was related to fertilizer-K rate. Based on visual ratings of 1 (slight lodging) to 5 (severe lodging) prior to harvest, lodging ratings averaged 4.8, 2.8, 2.0, 1.2, and 1.0 for RT 7321 FP with 0, 40, 80, 120, and 160 lb K_2O/ac application rates, respectively. Lodging was not observed in Diamond in 2021 or either of the cultivars in 2020. While K-rate treatment yield differences of the hybrid may have been enhanced by lodging, grain yield trends were similar to those observed in 2020, where rates of 80 and 120 lb K_2O/ac were required to achieve near-maximum yields for Diamond and the hybrid, respectively. 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 (RT Gemini 214 CL) than from Diamond in matching short-term site-years. Interestingly, the hybrids were more responsive to fertilizer-K in 2020 and 2021 than Diamond (average maximum increase of 47 bu./ac for Diamond, 65 bu./ac for RT 7521 FP in 2020, and 91 bu./ac for RT 7321 FP with lodging in 2021), which is 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.

In 2021, the tissue-K concentration of Y-leaves at the booting growth stage increased significantly with each increasing K application rate, ranging from 1.04 to 1.73%, but K concentration did not differ between the pure-line and hybrid cultivars (Table 3). Based on 5 site-years in 2018, Gruener et al. (2019) predicted a critical Y-leaf concentration (to achieve 95% relative yield) of 1.50% for samples collected 22 to 28 days after R1, which corresponds to when Y-leaves were sampled in 2021. This is consistent with the 96% relative yield and 1.46% Y-leaf K concentration (at booting) of Diamond when 80 lb K_2O/ac was applied in 2021. Near-maximum yields were expected from RT 7321 FP when 80 lb K_2O/ac was applied, based on a Y-leaf K concentration of 1.49% at the booting growth stage, but the observed relative yield of 86% was likely the result of yield lost to lodging in 2021 and not an accurate reflection of Y-leaf K concentration.

Practical Applications

Two 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. 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. 2019 are applicable for both pure-line and hybrid rice cultivars. The total aboveground K uptake data from 2020 indicates that the hybrid cultivar is better able to access and take up K when a moderate rate of potassium fertilizer is applied. 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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Literature Cited

DeLong, R.E., N.A. Slaton, C.G. Herron, and D. Lafex. 2021. Arkansas soil-test summary for samples collected in 2019. *In*: N.A. Slaton (ed.) Wayne E. Sabbe Arkansas Soil Fertility Studies 2020. University of Arkansas Agricultural Experiment Station Research Series. 675:5-22. Fayetteville.

Dobermann, A. and T.H. Fairhurst. 2000. Mineral deficiencies. *In*: Rice: Nutrient disorders and nutrient management. International Rice Research Institute, Makati City, Philippines. p. 40-119.

Gruener, C.E., N.A. Slaton, J.T. Hardke, T.L. Roberts, A.D. Smartt, and M.D. Coffin. 2019. Delineation of continuous, critical leaf potassium concentrations during reproductive growth for monitoring rice potassium status. *In*: R.J. Norman and K.A.K. Moldenhauer (eds.). B.R. Wells Arkansas Rice Research Studies 2018. University of Arkansas Agricultural Experiment Station Research Series. 659:283-289. Fayetteville.

Gruener, C.E., N.A. Slaton, T.L. Roberts, J.T. Hardke, and A.D. Smartt. 2020. Yield responses of pure-line and hybrid rice to potassium fertilization for long- and short-term trials. *In*: K.A.K. Moldenhauer, B. Scott, and J. Hardke (eds.). B.R. Wells Arkansas Rice Research Studies 2019. University of Arkansas Agricultural Experiment Station Research Series. 667:211-213. Fayetteville.

Hardke, J.T. 2021. Trends in Arkansas rice production, 2020. *In*: J. Hardke, X. Sha, and N. Bateman (eds.). B.R. Wells Arkansas Rice Research Studies 2020. University of Arkansas Agricultural Experiment Station Research Series. 676:11-18. Fayetteville.

Maschmann, E.T., N.A. Slaton, R.D. Cartwright, and R.J. Norman. 2010. Rate and timing of potassium fertilization and fungicide influence rice yield and stem rot. Agron. J. 102:163-170.

Norman, R.J., T.L. Roberts, N.A. Slaton, and A. Fulford. 2013. Nitrogen uptake efficiency of a hybrid compared with a conventional, pure-line rice cultivar. Soil Sci. Society Amer. J. 77:1235-1240. https://doi.org/10.2136/sssaj2013.01.0015

Slaton, N.A., B.R. Golden, R.J. Norman, C.E. Wilson, and R.E. DeLong. 2009. Correlation and calibration of soil potassium availability with rice yield and nutritional status. Soil Sci. Society Amer. J. 73:1192-1201. https://dx.doi.org/10.2136/sssaj2008.0200

Slaton, N.A., R.J. Norman, R.E. DeLong, S.D. Clark, R.D. Cartwright, and C.E. Parsons. 2010. Rice response to phosphorus and potassium fertilization. *In*: R.J. Norman and K.A.K. Moldenhauer (eds.). B.R. Wells Rice Research Studies 2009. University of Arkansas Agricultural Experiment Station Research Series. 581:295-304. Fayetteville.

Slaton, N.A., T.L. Roberts, R.J. Norman, C.G. Massey, R.E. DeLong, J. Shafer, and S.D. Clark. 2012. Rice response to nitrogen and potassium fertilizer rates. In: R.J. Norman and K.A.K. Moldenhauer (eds.). B.R. Wells Rice Research Studies 2011. University of Arkansas Agricultural Experiment Station Research Series. 600:292-297. Fayetteville.

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 and 9 in 2020 and 2021, respectively) 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 2020 and 2021.

	2020		2021	
Fertilizer-K rate	**Soil pH**	**Soil-test K**	**Soil pH**	**Soil-test K**
(lb K_2O/ac/y)		**(ppm)**		**(ppm)**
0	8.1	29 e[†]	8.1	34 d
40	8.0	37 d	8.1	37 d
80	8.0	43 c	8.1	44 c
120	7.9	52 b	8.0	58 b
160	7.9	64 a	8.1	70 a
mean	8.0	45	8.1	49
C.V.[‡] (%)	1.6	14.3	1.1	13.8
P-value	0.1428	<0.0001	0.3571	<0.0001

[†] Means in the same column followed by different letters are significantly different ($P \leq 0.10$).

[‡] C.V. = Coefficient of variation.

Table 2. Tissue-K concentration (%) and K uptake (lb K/ac) from whole, aboveground rice plants sampled at 50% heading 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 2020.

	Tissue K			K uptake			Grain yield		
Fertilizer-K rate	**Diamond**	**RT 7521 FP**	**K rate mean**	**Diamond**	**RT 7521 FP**	**K rate mean**	**Diamond**	**RT 7521 FP**	**K rate mean**
(lb K_2O/ac/y)		--------------(%)--------------			-----------(lb K/ac)-----------			------------(bu./ac)------------	
0	0.79	0.74	0.77 c[†]	55	49	52 c	131	116	124 c
40	--	--	--	--	--	--	163	158	161 b
80	1.30	1.35	1.33 b	116	153	135 b	168	161	165 b
120	--	--	--	--	--	--	172	181	177 a
160	1.94	1.85	1.89 a	176	190	183 a	174	180	177 a
Cultivar mean	1.34	1.31	--	116	131	--	162	160	--
K rate		<0.0001			<0.0001			<0.0001	
Cultivar		0.4961			0.1497			0.4782	
Interaction		0.4355			0.2265			0.1224	
C.V.[‡] (%)		11.2			27.2			8.8	

[†] Means in the same column followed by different letters are significantly different ($P \leq 0.10$).

[‡] C.V. = Coefficient of variation.

Table 3. Y-leaf tissue-K concentration (%) from rice plants sampled at the booting growth stage (*n* = 6) and grain yield (*n* = 9) 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 2021.

	Tissue K			Grain yield		
Fertilizer-K rate	**Diamond**	**RT 7321 FP**	**K rate mean**	**Diamond**	**RT 7321 FP**	**K rate mean**
(lb K_2O/ac/yr)	--------------(%)--------------			------------(bu./ac)------------		
0	0.99	1.08	1.04 e†	111 D‡	58 E	84
40	1.32	1.36	1.34 d	144 B	104 D	124
80	1.46	1.49	1.47 c	156 AB	128 C	142
120	1.62	1.60	1.61 b	162 A	149 AB	155
160	1.80	1.66	1.73 a	157 AB	149 AB	153
Cultivar mean	1.44	1.44	--	146	119	--
K rate		<0.0001			<0.0001	
Cultivar		0.9938			<0.0001	
Interaction		0.2772			0.0062	
C.V.§ (%)		9.3			13.4	

† Different lowercase letters next to means in the same column indicate significant differences ($P \leq 0.10$).

‡ Different uppercase letters next to means indicate significant differences within cultivar and K-rate treatment combinations ($P \leq 0.10$).

§ C.V. = Coefficient of variation.

Summary of N-STaR Nitrogen Recommendations in Arkansas During 2021

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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 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 2021 were summarized by county and soil texture, totaled 21 fields across 9 Arkansas counties, and were from 6 clay and 15 silt loam fields. Depressed sample submissions were again observed likely due to another wet spring and lingering effects of the COVID-19 pandemic. The N-STaR N-rate recommendations for samples were compared to the producer's estimated N rate, the 2021 Recommended Nitrogen Rates and Distribution for Rice Cultivars in Arkansas, 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. In all 3 comparisons, county, but not soil texture, was a significant factor ($P < 0.04$) in observed decreases in N recommendation strategies demonstrating variations in the soil's ability to supply N across the state. Further stressing the potential N cost savings opportunities, reductions greater than 30 lb N/ac were recommended by N-STaR in 71%, 50%, and 74% 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

To evaluate the effect of the N-STaR program in Arkansas, samples submitted to the N-STaR Soil Testing Lab for the 2021 growing season were categorized by county and soil texture. 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 2021 Recommended Nitrogen Rates and Distribution for Rice Cultivars in Arkansas found in the 2021 Rice Management Guide (Hardke et al., 2021), 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 21 producer fields across 9 Arkansas counties during the 2021 production year, which is only 6.9% of the 304 fields sampled in 2013 when the program was

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initiated and costs were partially subsidized. Lawrence County ranked 1st in Arkansas rice production acres (USDA-FSA, 2021), and Lonoke County, ranked 4th, submitted samples from 8 and 6 fields, respectively, while samples from other counties were from just a single field. All samples from Lawrence County were submitted by a single producer. Samples from 8 of the 21 total fields were submitted by local Agriculture Extension Agents and represented Rice Research Verification fields across the state. The average number of fields submitted by client was 2.1, with only 2 clients submitting samples from more than a single field. All 2021 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 15 silt loam fields and 6 clay fields (Table 1).

Just like the past few years, 2021 hit farmers with a wet early spring, which only allowed small planting windows scattered across the state and an all too familiar rush when the ground was dry enough for planting. When rains and cooler temperatures did finally break, 2021 Arkansas planted rice acreage totaled 1.21 million acres, down from the 1.44 million acres in 2020 (http://www.nass.usda.gov). Another wet spring coupled with the rush to get rice planted, favorable N prices, and the continuation of the COVID-19 pandemic likely led to decreased numbers of samples that would have been submitted for N-STaR analysis. Lawrence County had the highest planted rice estimates (http://www.nass.usda.gov) 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 not found to be a significant factor. However, as in previous years, county was a significant factor ($P < 0.0418$) in fields where N-STaR called for a decrease in N rate suggesting that some areas of the state may be prone to N savings potential due to cropping systems and higher native soil-N levels (Fig. 1). There were no increases in N rate 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 21 fields in this comparison, there was a decrease in N recommendation for 19 fields (91% of submitted fields) with an average decrease of 45.5 lb N/ac. No change in N recommendation was found for 1 clay field, and 1 silt loam field (5% of those submitted) had an increase in N recommendation of 15.0 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.

Three 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 18 fields that were compared, there was a decrease in N recommendations for 17 fields (94% of the compared fields) with an average decrease of 38.5 lb N/ac (Table 2). No change in N recommendation was found for 1 field, while no fields had an increase in N recommendation. This comparison, like the standard rate comparison, found soil texture insignificant and county significant ($P < 0.0418$) when N-STaR recommended a decreased N rate resounding that certain areas of the state may have larger residual soil-N reserves.

When the N-STaR recommendation was compared to the 2021 Recommended Nitrogen Rates and Distribution for Rice Cultivars in Arkansas, 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 while 1 field listed a cultivar that was not included in the 2021 Recommended Nitrogen Rates and Distribution for Rice Cultivars in Arkansas list, so both were excluded from this comparison. There was a decrease in the N recommendation for 18 fields (95% of the 19 fields) with an average decrease of 45.8 lb N/ac (Table 3). One silt loam field (5% of compared fields) had an increase in N recommendation of 30 lb N/ac. In this comparison county, but not texture, was again found to be a significant factor ($P < 0.0402$) for fields with N-STaR-suggested reduced N rates.

In all 3 comparisons, N-STaR proposed decreases as high as 90 lb N/ac in some fields. Decreases greater than 30 lb N/ac were proposed in 71%, 50%, and 74% 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 the standard comparison and 30 lb N/ac in the producer's estimate comparison.

Practical Applications

Despite decreased 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. 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 when fertilizer costs cycle upwards if farmers are aware of the potential cost reductions possible with N-STaR sampling.

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Literature Cited

Davidson, J.T, 2016. Validation of N-STaR Nitrogen Rate Recommendations and Evaluation of N-STaR Soil Sampling Procedures for Clay Soils in Arkansas. MS Thesis. Univ. of Arkansas. Fayetteville.

Fulford, A.M., T.L. Roberts, R.J. Norman, N.A. Slaton, C.E. Wilson Jr., T.W. Walker, D.L. Frizzell, C.E. Greub, C.W. Rogers, S.M. Williamson, M.W. Duren, and J. Shafer. 2013. Evaluation of the Illinois Soil Nitrogen Test and the Nitrogen-Soil Test for Rice Grown on Clayey Soils. *In*: R.J. Norman and K.A.K. Moldenhauer (eds.) B.R. Wells Rice Research Studies 2012. University of Arkansas Agricultural Experiment Station Research Series 609:204-212. Fayetteville.

Hardke, J.T., L. T. Barber, N. R. Bateman, T. R. Butts, M. K. Hamilton, C. G. Henry, G. M. Lorenz, R. S. Mazzanti, J. K. Norsworthy, T.L. Roberts, Y. A. Wamishe. 2021. 2021 Rice Management Guide University of Arkansas System Division of Agriculture's Cooperative Extension Service. Accessed 27 Aug. 2021. Available at: http://www.uaex.uada.edu/farm-ranch/crops-commercial-horticulture/rice/

Khan, S.A., R.L. Mulvaney, and R.G. Hoeft. 2001. A simple soil test for detecting sites that are nonresponsive to nitrogen fertilization. Soil Sci. Soc. Am. J. 65:1751–1760.

Roberts, T.L., R.J. Norman, N.A. Slaton, and C.E. Wilson Jr. 2009. Changes in alkaline hydrolyzable nitrogen distribution with soil depth: Implications for fertilizer correlation and calibration. Soil Sci. Soc. Am. J. 73:2143-2150.

Roberts, T.L., W.J. Ross, R.J. Norman, N.A. Slaton and C.E. Wilson, Jr. 2011. Predicting nitrogen fertilizer needs for rice in Arkansas using alkaline hydrolyzable-nitrogen. Soil Sci. Soc. Am. J. 75:1-12.

USDA-NASS. 2022. United States Department of Agriculture National Agricultural Statistics Service. Accessed 26 Apr. 2022. Available at: https://quickstats.nass.usda.gov/

Table 1. Distribution and change in nitrogen (N) fertilizer rate compared to the standard recommendation, producer's estimated N rate, and the 2021 Recommended Nitrogen Rates and Distribution for Rice Cultivars in Arkansas based on soil texture.[a]

Soil Texture	Number of Fields Submitted	Decreased N-STaR Recommendation		Increased N-STaR Recommendation		No Change in Recommendation
		Number of Fields	Mean N Decrease (lb N/ac)	Number of Fields	Mean N Increase (lb N/ac)	
Standard soil texture						
Clay	6	6	49.2	-	-	-
Silt Loam	15	13	43.8	1	15.0	1
Total	21	19	45.5	1	15.0	1
Producer estimate						
Clay	4	4	30.0	-	-	-
Silt Loam	14	13	41.2	-	-	1
Total	18	17	38.5	-	-	1
Cultivar						
Clay	6	6	49.2	-	-	-
Silt Loam	13	12	44.2	1	30.0	-
Total	19	18	45.8	1	30.0	-

[a] Failure to include a producer's estimated N rate excluded 3 fields from the producer's estimate comparison. In the cultivar comparison, failure to list cultivar excluded 1 field while another was excluded because the selected cultivar was not included in the 2021 Recommended Nitrogen Rates and Distribution for Rice Cultivars in Arkansas list

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		Increased N-STaR Recommendation		No Change in Recommendation
		Number of Fields	Mean N Decrease	Number of Fields	Mean N Increase	
			(lb N/ac)		(lb N/ac)	
Arkansas	1	-	20.0	-	-	-
Chicot	1	1	90.0	-	-	-
Jefferson	1	1	5.0	-	-	-
Lawrence	8	8	30.6	-	-	-
Lee	1	1	10.0	-	-	-
Lonoke	5	5	57.0	-	-	-
Monroe	1	-	-	-	-	1
Total	18	17	38.5	-	-	1

[a] Three fields were excluded from this analysis because no estimated N rate was listed on the sample submission sheet.

Table 3. Distribution and change in nitrogen (N) rate compared to the 2021 Recommended Nitrogen Rates and Distribution for Rice Cultivars in Arkansas by cultivar.[a]

Cultivar	Number of Fields Submitted	Decreased N-STaR Recommendation		Increased N-STaR Recommendation		No Change in Recommendation
		Number of Fields	Mean N Decrease	Number of Fields	Mean N Increase	
			(lb N/ac)		(lb N/ac)	
DG263L	1	-	-	1	30	-
Diamond	8	8	41.9	-	-	-
PVL01	1	1	20.0	-	-	-
RT 7321 FP	2	2	65.0	-	-	-
RT 7521 FP	1	1	45.0	-	-	-
RT XP753	6	6	49.2	-	-	-
Total	19	18	45.8	1	30	-

[a] One field did not list a cultivar on their N-STaR Sample Submission Sheet and 1 field listed a cultivar that was not included in the recommendation list, so both fields were excluded from the analysis.

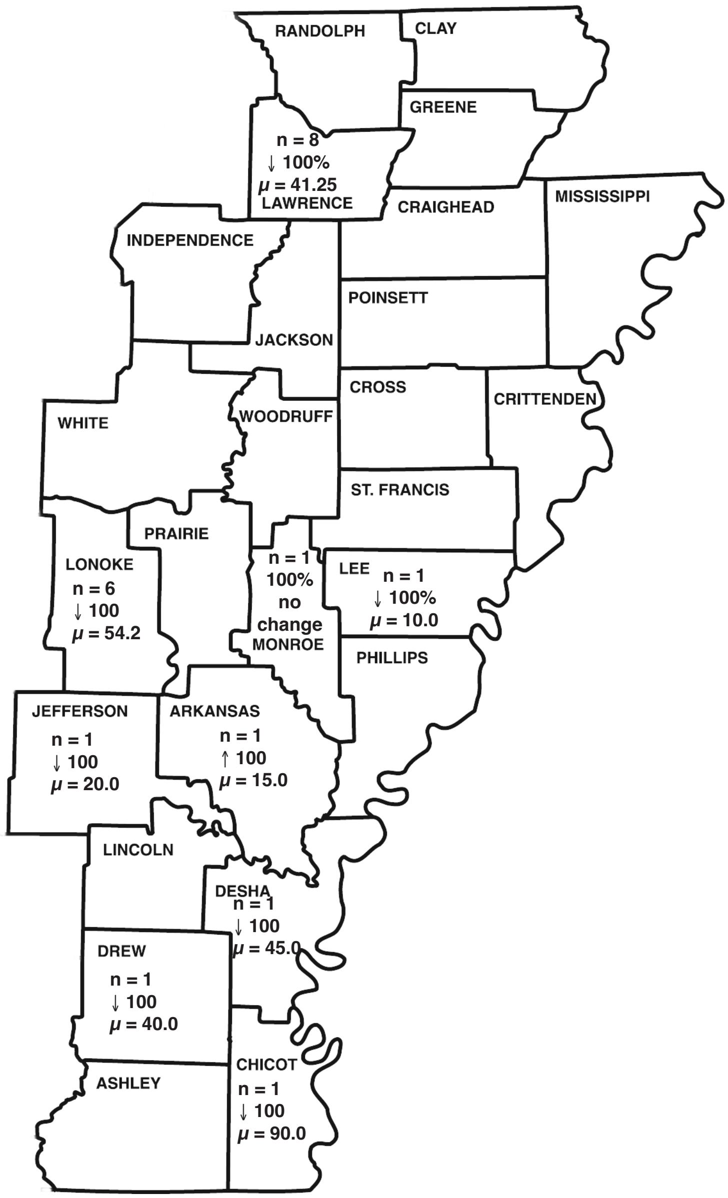

Fig. 1. The number of fields submitted, percent, and mean decrease and increase in N-STaR nitrogen (N) recommendation (lb N/ac) by county compared to the standard recommendation.

Development and Validation of Rapid Visco Analyzer Method for Rapid Determination of Gelatinization Temperatures of Arkansas Rice Cultivars

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Abstract

Differential scanning calorimetry (DSC) is a thermoanalytical method used to measure gelatinization temperature (GT) and functions by measuring heat flows associated with gelatinization as a function of temperature. While the method is highly accurate and precise, it is also time-consuming, expensive, and requires a high level of expertise. As a result, a new method that is faster, less expensive, and easier to use has been introduced by Dang and Bason (2014), which utilizes the Rapid Visco Analyser (RVA), an instrument that measures viscosity as a function of temperature. Still, rice cultivars grown in Arkansas have relatively narrow GT ranges, and it was necessary to determine whether the GT was being over or underestimated using statistical analysis. Therefore, the objective of the study was to determine the accuracy and precision of the RVA method in comparison to the DSC method for measuring GTs of rice cultivars produced in Arkansas. The study examined Arkansas cultivars harvested in 2019 and 2020 in both milled and brown kernels. Additionally, tests were performed at an industrial facility to validate the results obtained in our laboratory. Overall, the study showed a significant statistical difference between the GT determined using the RVA method and the GT determined using the DSC method. The GT determined using RVA consistently overestimated GT on every cultivar tested; therefore, a calibration equation was developed to correct for the overestimation. Overall, the RVA method was precise. The tests done in the industrial laboratory validated the calibration equation for accurate measurement of GT using RVA without any effect of difference in technicians.

Introduction

Gelatinization temperature (GT) of rice refers to the temperature at which the intermolecular structure of starch granules in rice begins to break down, resulting in irreversible changes in physicochemical and functional properties (Batey, 2007; Beckles and Thitisaksakul, 2014). The GT of rice is commonly used to determine cooking duration. Cultivars with high GTs generally require more time to cook than cultivars with lower values. In the rice industry, GT is frequently used to maximize rice quality while minimizing energy use; particularly when parboiling rice, the GT must be reached for the starch granules to completely melt and eliminate any cracks present in the rice grains (Bauer and Knorr, 2004; Ituen and Ukpakha, 2011). However, the application of temperatures over the established GT results in increased energy costs and loss of tenderness and color of rice (Bello et al., 2012).

Gelatinization temperature is heavily dependent on the chemical composition of rice, especially the varying ratio and molecular configurations of amylose (AMY) and amylopectin (AP) in the starch component of different cultivars (Juhász and Salgó, 2008). Amylose molecules are made of mostly linear glucose monomers with a few long branches. Amylopectin molecules are also composed of linear glucose monomers but are highly branched in comparison to AMY (Beckles and Thitisaksakul, 2014; Li et al., 2017). The crystalline structure of starch is only associated with AP, while amorphous regions are mostly associated with AMY (Singh et al., 2006). There is a correlation between the AP unit-chain distribution and GT and a negative correlation between AMY content and GT. These two correlations are, however, likely independent of each other (Fredriksson et al., 1997).

Soil and climatic conditions, as well as processing factors, affect rice starch structure and GT, necessitating routine measurements of GT (Fan et al., 1999; Cameron et al., 2008). Differential scanning calorimetry (DSC) is a commonly used method to determine GTs of starch-based foods (Biliaderis et al., 1980). The DSC instrument functions by heating the sample and reference cells at a constant rate over a specified temperature range and measuring the heat flow into the sample (Bergman et al., 2004). The DSC then creates a thermogram from which the gelatinization enthalpies as well as onset (T_0), peak (T_p), and conclusion (T_c) GTs are extracted (Karapantsios et al., 2000). Traditionally, the rapid visco analyzer (RVA) is used to measure the pasting temperature (PT) of rice. Pasting temperature, the temperature reached when the melted starch granule swells, occurs soon after gelatinization and marks a measurable viscosity increase; therefore, PT overestimates GT for a given cultivar (Thomas and Atwell, 1999). Therefore, it is possible the RVA method was still under or overestimating the GT of cultivars within a certain GT range. Rice cultivars grown in the state of Arkansas have relatively narrow GT ranges. Therefore, there is a need to determine whether GT values are being over or underestimated for rice cultivars grown in Arkansas when using an RVA method utilizing robust statistical analysis.

The main goal of this research was to determine the accuracy and precision of an RVA method in comparison to the DSC method for measuring GTs of rice cultivars produced in Arkansas. The specific objectives were to 1) develop a calibration model for

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accurate and precise measurements of GT using RVA; and (2) validate the calibration model by performing field testing at an industrial (commercial) rice processing facility.

Procedures

Thirty-four rice lots were harvested at varying moisture contents from RiceTec, Inc. show plots at Harrisburg, Ark. in September 2019 and again in September 2020. From the lots harvested in the year 2019, 5 Arkansas rice cultivars were selected to be analyzed: Diamond, V 7522, RT 7521, RT 7301, and XP753. In the year 2019, both brown and milled rice samples of all 5 cultivars were analyzed. However, only milled Diamond, RT 7301, and XP753 samples were analyzed from samples harvested in the year 2020. Additionally, these 3 cultivars were sent to a Riceland industrial facility in Stuttgart, Ark. for GT measurement using RVA and DSC in a commercial setting.

Rice Flour Sample Preparation

After the harvested rice was transported to the Department of Food Science building in Fayetteville, Ark., the rice was stored at 39.2 °F. Once it was time for processing, the rough rice was removed from storage and brought to room temperature. The rough rice was cleaned using a dockage tester (XT4, Carter-Day, Minneapolis, Minn.) and then dried to 12.5% moisture content (wet basis). The rough rice was dehulled using a laboratory sheller (THU 35B-3T, Satake, Tokyo, Japan). Brown rice flour samples were then obtained by grinding the dehulled rice with a laboratory mill (cyclone sample mill, Udy Corp., Ft. Collins, Colo.). From the brown rice samples, milled rice sub flour samples were milled for 30 seconds in a McGill No. 2 laboratory mill and placed on a shaker table to separate head rice from broken kernels before the head rice was ground into rice flour. Moisture content was then determined for each of the samples using an air-oven method according to the AACCI Approved Method 44-15.02 (AACCI, 2009). In this method, approximately 0.09-0.11 oz of rice flour was dried in an oven at 266 °F for 1 hour then placed in a desiccator for 30 minutes, then sample weight differences before and after drying were used to determine percent moisture content.

Differential Scanning Calorimetry Method

The gelatinization temperature of each rice flour sample was found using a differential scanning calorimeter (Pyris Diamond, Perkin-Elmer Instruments, Shelton, Conn.). In the DSC method, 0.0016 oz of rice flour was placed into the sample pan along with 0.00027 fl oz of deionized water added through a microsyringe (corrected to 12% moisture content in wet basis). The samples were incubated at room temperature for one hour. The slurry was held at 77 °F for 5 minutes, then heated from 77 to 248 °F at 50 °F/min. The instrument was calibrated using indium. For each cultivar, tests were performed in duplicate.

Rapid Visco Analyzer Method

The gelatinization temperature for each sample was also determined using a Rapid Visco Analyzer (Model 4, Perten Instruments, Springfield, Ill.). In the RVA method, 0.21 oz of rice flour corrected to 12% moisture content in wet basis was put into 0.81 fl oz of deionized water. The slurry was held at 122 °F for 5 minutes, then heated from 122 to 203 °F at 37 °F /min. For each cultivar, tests were performed in duplicate.

Statistical Analysis

Data were analyzed for analysis of variance (ANOVA) using JMP Pro 16 a statistical software (JMP Pro 16, SAS Institute, Cary, N.C.) with complete randomization. Analysis of variance was done to see any effect of cultivar, type of rice, and replications on the gelatinized temperature using RVA and DSC. Differential scanning calorimetry GTs were used to compare the accuracy of RVA. Moreover, the precision of the RVA was checked using the two replications. Correlation analyses were done to determine the calibration model that was used to make any further adjustments in the RVA readings to reduce the over or underestimation of GTs. Model validations were done using tests performed in the commercial facility.

Results and Discussion

Analysis of variance showed that instrument type did have a statistically significant effect on GT results at a 95% level of significance (Table 1). Therefore, the RVA method and DSC method gave significantly different results. The variables cultivar type and rice type also had a statistically significant effect on GT results, whereas, replications did not.

In both harvest years, the GT determined using the RVA method consistently overestimated the GT determined using the DSC method for a particular cultivar, regardless of rice type (Tables 2 and 3). Dang and Bason (2014) also found similar results where RVA consistently overestimated the GT of rice cultivars as compared to the DSC method. As far as the precision is concerned, RVA GT readings are highly precise as depicted by the non-significance of replication in the analysis of variance (Table 1). Dang and Bason (2014) reported the same for RVA GT readings.

Overall, brown rice had higher GT as compared to white rice, as brown rice has an extra layer of bran that leads to higher gelatinization temperatures for providing more heat to starch in the endosperm to gelatinize. As for the cultivars, RT 7301 and XP 753 had higher GT values for both years, whereas Diamond had the lowest GT values irrespective of the type of equipment used to measure GT (Tables 2 and 3).

The calibration model using correlation analysis was developed as mentioned in Eq. 1. The coefficient of determination (R^2) was 0.92, suggesting an acceptable line of best fit (Fig. 1).

$$DSC\ (GT) = 1.2577 * RVA\ (GT) - 46.4510 \qquad \text{Eq. 1}$$

where DSC (GT) and RVA (GT) are the estimated gelatinization temperature by differential scanning calorimeter and measured gelatinization temperature by rapid visco analyzer in °F, respectively.

For model validation, the analysis of variance showed that two variables, the instrument used and the cultivar type, had a significant effect on GT (Table 4). However, variables such as the technician performing the test and the replication did not significantly affect GT. The results obtained from tests performed at the industrial facility further suggested that the RVA method repeatedly overestimated the GT obtained by the DSC method (Table 5). Therefore, adjustments to the GT values of RVA need to be made to be accurate. Different technicians using RVA and DSC did not cause any significant changes to the results and the readings were precise as well. Commercial test data to the predicted values obtained using Eq. 1 were fitted (Fig. 2). An R^2 value of 0.98 signifies a good prediction using the calibration equation.

Practical Applications

Compared to the RVA, the DSC is a more expensive instrument that is more time-consuming and can give inconsistent results (Bergman et al., 2004). As a result, the Cereal and Grains Association has published a study on a method for determining GT using the RVA (Dang and Bason, 2014). This study concluded that the RVA overestimated GT values, which were corrected using the calibration equation. The RVA GT values were highly precise. The calibration equation was validated with commercial test data. The RVA can be used as a standalone method to measure the gelatinized temperature of rice flour. This method is easier and quicker to use and will be suitable for industrial as well as educational applications.

Acknowledgments

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Literature Cited

AACC International. 2009. Approved Methods of Analysis, 11th Ed. Method 44-15.02. Available online only. AACC International: St. Paul, Minn.

Batey, I.L. 2007. Interpretation of RVA curves. *In*: Crosbie, G.B. and A.S. Ross (eds). The RVA Handbook, 19-31. St Paul, Minn.: AACC International.

Bauer, B.A. and D. Knorr. 2004. Electrical conductivity: a new tool for the determination of high hydrostatic pressure-induced starch gelatinization. Innov. Food Sci. Emerging Technol. 5:437-442.

Beckles, D.M. and M. Thitisaksakul. 2014. How environmental stress affects starch composition and functionality in cereal endosperm. Starch 66: 58-71.

Bello, M.O., R.J. Aguerre, M.P. Tolaba, and C. Suárez. 2012. Effect of hydrothermal conditions on translucence of milled rice. *In*: J.C. Caivano and M.P. Buera (eds.) Color in Food: Technological and Psychophysical Aspects. 63-70. London: CRC Press.

Bergman, C.J., K.R. Bhattacharya, and K. Ohtsubo. 2004. Rice end-use quality analysis. *In*: E.T. Champagne (ed.) Rice Chemistry and Technology, 415-472. St. Paul, Minn.: AACC International.

Biliaderis, C.G., T.J. Maurice, and J.R. Vose. 1980. Starch gelatinization phenomena studied by differential scanning calorimetry. Food Sci. 45:1669-1680.

Cameron, D.K., Y.J. Wang, and K.A. Moldenhauer. 2008. Comparison of physical and chemical properties of medium-grain rice cultivars grown in California and Arkansas. Food Sci. 73:72-78.

Dang, J.M.C. and M.L. Bason. 2014. AACCI approved methods technical committee report: collaborative study on a method for determining the gelatinization temperature of milled rice flour using the rapid visco analyser. Cereal Foods World 59:31-34.

Fan, J., B.P. Marks, M.J. Daniels, T.J. and Siebenmorgen. 1999. Effects of postharvest operations on the gelatinization and retrogradation properties of long-grain rice. Trans. ASAE. 42:727-731.

Fredricksson, H., J. Silverio, R. Andersson, A.C. Eliasson, and P. Aman. 1997. The influence of amylose and amylopectin characteristics on gelatinization and retrogradation properties of different starches. Carbohydr. Polym. 35:119-134.

Ituen, E.U. and A.C Ukpakha. 2011. Improved method of par-boiling paddy for better quality rice. World J. Appl. Sci. Technol. 3:31-40.

Juhász, R. and A. Salgó. 2008. Pasting behavior of amylose, amylopectin, and their mixtures as determined by RVA curves and first derivatives. Starch 60:70-80.

Karapantsios, T.D., E.P. Sakonidou, and S.N. Raphaelides. 2000. Electrical conductance study of fluid motion and heat transport during starch gelatinization. Food Sci. 65:144-150.

Li, M., S. Dhital, and Y. Wei. 2017. Multilevel structure of wheat starch and its relationship to noodle eating qualities. Comp. Rev. Food Sci. Food Safety 16:1042-1055.

Singh N., L. Kaur, K.S. Sandhu, J. Kaur, and K. Nishinari. 2006. Relationships between physicochemical, morphological, thermal, rheological properties of rice starches. Food Hydrocoll. 20:532-542.

Thomas, D.J. and W.A. Atwell. 1999. Starches. St Paul, Minn.: Eagan Press.

Table 1. Analysis of variance with equipment, rice type, cultivar, and replication as factors.

Factors	Levels	*P*-value
Equipment	Rapid visco analyzer and Differential scanning calorimetry	<0.0001[a]
Rice type	milled and brown	<0.0001[a]
Cultivar	Diamond, RT 7301, RT 7521, V 7522 and XP 753	<0.0001[a]
Replication	1 and 2	0.8842

[a] Statistical significance checked at α = 0.05.

Table 2. Mean gelatinized temperature (GT) with standard deviation using rapid visco analyzer and differential scanning calorimetry of 5 Arkansas rice cultivars in 2019.

Cultivar	Rice type	Rapid visco analyzer GT	Differential scanning calorimetry GT
		(°F)	(°F)
Diamond	Brown	166.15 ± 0.32	162.07 ± 1.57
Diamond	Milled	163.81 ± 0.06	160.84 ± 0.10
RT 7301	Brown	168.67 ± 0.19	164.63 ± 0.29
RT 7301	Milled	166.82 ± 0.25	163.27 ± 0.23
RT 7521	Brown	167.54 ± 0.25	164.10 ± 0.18
RT 7521	Milled	166.15 ± 0.32	162.83 ± 0.02
V 7522	Brown	167.00 ± 1.02	164.21 ± 0.15
V 7522	Milled	165.02 ± 0.25	161.62 ± 0.43
XP 753	Brown	168.31 ± 0.19	166.50 ± 1.16
XP 753	Milled	166.69 ± 0.06	163.13 ± 0.03

Table 3. Mean gelatinized temperature (GT) with standard deviation using rapid visco analyzer and differential scanning calorimetry of 3 Arkansas rice cultivars in 2020.

Cultivar	Rice type	Rapid visco analyzer GT	Differential scanning calorimetry GT
		(°F)	(°F)
Diamond	Milled	158.86 ± 0.32	153.04 ± 0.32
RT 7301	Milled	165.20 ± 0.00	160.15 ± 0.47
XP 753	Milled	164.53 ± 0.06	159.79 ± 0.17

Table 4. Analysis of variance for commercial tests with equipment, technician, cultivar, and replication as factors.

Factors	Levels	*P*-value
Equipment	Rapid visco analyzer and Differential scanning calorimetry	<0.0001[a]
Technicians	1 and 2	0.3383
Cultivar	Diamond, RT 7301 and XP 753	<0.0001[a]
Replication	1 and 2	0.2051

[a] Statistical significance checked at α = 0.05.

Table 5. Matched pair analysis for gelatinized temperature from rapid visco analyzer and differential scanning calorimetry.

Year	RVA-DSC GT
	(°F)
2019	3.29 ± 0.66
2020	5.20 ± 0.56
2020 (Commercial tests)	6.10 ± 0.48

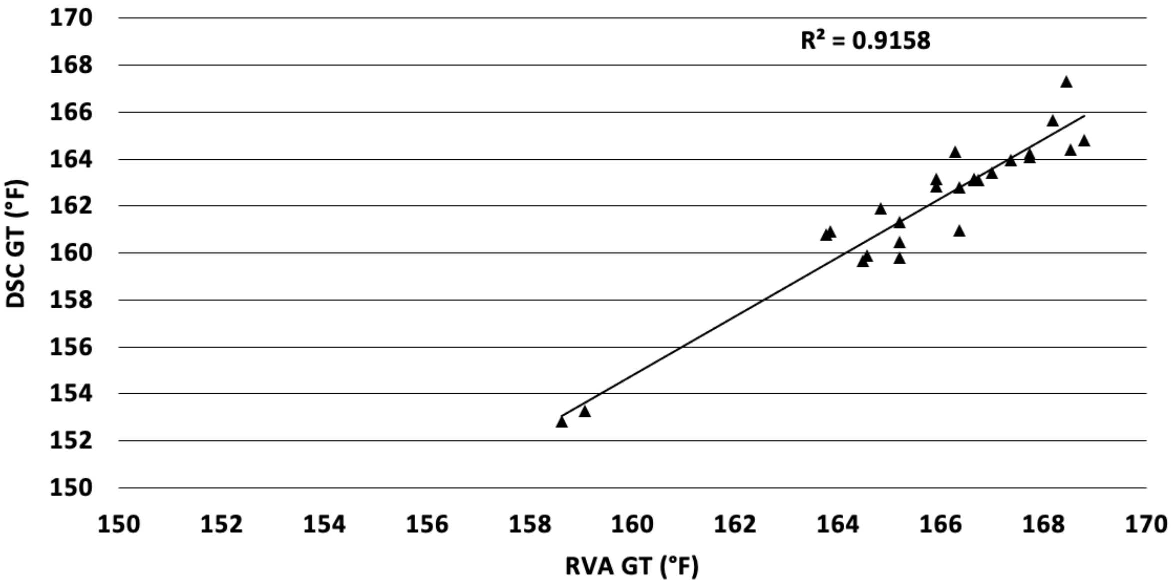

Fig. 1. Gelatinization temperature (GT) determined by rapid visco analyzer (RVA) and differential scanning calorimetry (DSC) for 2019 and 2020 samples.

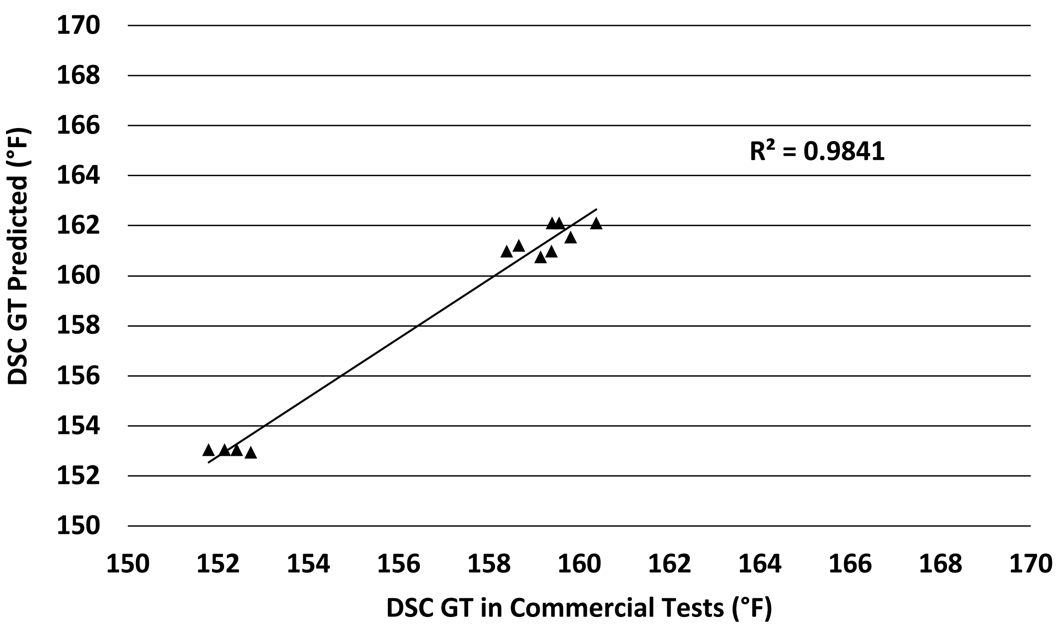

Fig. 2. Bivariate fit of gelatinization temperature (GT) data determined by differential scanning calorimetry (DSC) and predicted values as obtained using calibration equation (for tests performed at an industrial facility using the 2020 rice samples).

World and U.S. Rice Baseline Outlook, 2021–2031

A. Durand-Morat[1] *and S.K. Bairagi*[1]

Abstract

The marketing year 2020 marked a record for global rice production, consumption, trade, and stocks. Despite the global rice surplus, prices in the international market were firm on average, primarily for long-grain rice from Thailand and medium-grain rice from California. The most relevant development in the marketing year 2020 was the outstanding performance of Indian exports, which surpassed 20 million metric tons (mmt). Over the next decade, the international (free on board or FOB) price of long-grain rice, represented by Thailand's 100% B rice, is projected to increase on average by 1% annually, while the international price of medium-grain rice, represented by the U.S. No. 2 from California, is projected to grow 1.7% annually. World rice production and consumption are projected to expand a cumulative 6.4% and 9.0% over the next decade, with India experiencing the largest expansion in both areas. Global rice trade is projected to increase significantly and reach 60 mmt by the end of the projected period.

Introduction

The latest USDA data indicates that global rice production has outpaced consumption by almost 9 million metric tons (mmt) in the marketing year (MY) 2020, pushing global stock levels to their highest nominal level on record. Despite such a large surplus, the export price for Thai 100% B long-grain rice reached its highest level in the last seven years (USDA-ERS, 2022), reflecting supply constraints that undermined the competitiveness of that origin. Asia continues to dominate the global rice market and accounted for 90% of production, 86% of consumption, 95% of stocks, and 84% of global exports in 2020. Around 10% of the global production of rice is traded internationally, which indicates that rice remains thinly traded compared to other field crops. However, the importance of international rice trade is growing, considering that only 7% of the crop was traded across borders a decade ago.

Arguably the most important development of MY 2020 was the share size of India's exports, reaching a record volume of 20 mmt or 40% of global rice exports. Granted, India has been the largest (and by far) rice exporter for 9 years in a row, but the increase in exports in MY 2020 was unexpected. To put India's MY 2020 export volume in perspective, it represented an increase of 60% relative to MY 2019 (which was the largest export volume on record until then), and a 7-fold increase relative to the volume India exported a decade ago. Other top exporters in MY 2020 included Vietnam (6.3 mmt), Thailand (5.9 mmt), Pakistan (3.9 mmt), and the U.S. (3.0 mmt). China has become an important rice exporter in the last few years, having a particular effect on the medium-grain segment with very competitive prices that facilitated its dominance in several markets in the Middle East (e.g., Turkey and Egypt) and Puerto Rico.

On the import side, China imported 4.5 mmt of rice in MY 2020, marking a sharp increase relative to the 2.6 mmt imported in MY 2019, making China the largest net (imports minus exports) importer in MY 2020. The Philippines maintained its status as the second-largest importer of rice in MY 2020. The changes to its importation laws, particularly the introduction of the Rice Tariffication Law in February 2019, facilitated the involvement of private traders and have resulted in a significant increase in the Philippines' rice imports in the last 3 years. Finally, it is worth noting the increase in Vietnamese rice imports, primarily paddy rice from Cambodia and even milled rice from India, which in part facilitated Vietnam's export activities.

Prices in the global rice market were mixed in MY 2020. Prices from most Asian origins decreased, while at the same time, India and Pakistan were the most price competitive among the main Asian origins. To illustrate, India's 5% long-grain rice sold at a US$ 140/mt discount over Thai 100% B long-grain rice in February 2021, and at a $50/mt discount in December 2021 (USDA-ERS, 2022). The U.S. and Mercosur long-grain rice are not price competitive vis-à-vis the main Asian origins, with an average margin of $162/mt between U.S. 5% long-grain and Thai 100% B long-grain rice in 2021.

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).

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The historical rice data come from USDA-FAS (2022a, 2022b) and USDA-ERS (2022). The macroeconomic data (e.g., gross domestic product, exchange rate, and population growth) come from IHS Markit 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 2022 about the general economy, agricultural policies, weather, and technological change. The basic assumptions are a continuation of existing policies, current macro-economic 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's 100% B rice, is projected to increase on average 1% annually and average $486/mt by 2029–2031 relative to $449/mt observed in the last three years (2018–2020) (Fig. 1; Table 1). Similarly, the international price of medium-grain[4] rice, represented by the U.S. No. 2 from California, is projected to grow 1.7% annually on average over the next decade and reach $1039/mt in 2029–2031 relative to $880/mt in 2018–2020 (Fig. 1; Table 1). We project a decrease in the international price of long-grain rice in the very short run, pushed by competitive pricing out of India, and a steady increase thereafter. Similarly, the price of medium-grain rice is also projected to reach record levels in the ongoing 2021 marketing year, in part due to the decrease in U.S. production, which in 2021 recorded the lowest production of medium- and short-grain rice (47.2 million cwt) of the last 15 years. While other countries such as Australia and China are expected to expand medium-grain exports in the short run, prices remain firm in line with strong demand.

The price gap between U.S. and Thai long-grain rice is expected to increase in the short run and hover around $200/mt, pushed by a projected small U.S. crop and good production and supply perspectives for Thailand and Asia in general. In the long run, the price gap will decrease but is likely to remain above $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.

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 expands by 32 mmt or 6.4% over the next decade, reaching around 533 mmt in 2029–2031, 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 35% of the production gain in the coming decade, followed by Thailand (9%), Bangladesh (8%), Vietnam (7%), and Indonesia (7%). In Africa, the largest gains in production are projected for Tanzania and Nigeria. In contrast, rice production is projected to decline in China (-4.3 mmt), and also in Japan, South Korea, Taiwan, and Brazil. Total U.S. rice production is projected to increase by 560 tmt over the same period, equivalent to an average annual growth of 0.6% (Table 3; Fig. 3).

Global rice consumption is projected to increase by 44 mmt, reaching 536 mmt on average in 2029–2031 (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 64.4 kg/person in 2018–2020 to 63.4 kg/person in 2029–2031. 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 aging populations and increased health-consciousness cause 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, followed by Bangladesh (7%), Nigeria (6%), and the Philippines (4%). Regionally, West Africa, more specifically ECOWAS,[5] accounts for roughly a quarter of the projected consumption growth over the next decade. United States rice domestic use increases by 623 tmt over the next decade, reaching an average of 7.3 mmt in 2029–2031 (Table 3; Fig. 3).

We project that global rice trade will expand by 14.3 mmt or 2.5% annually over the next 10 years, reaching 60.3 mmt on average in 2029–2031 compared to 46.0 mmt in 2018–2020 (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 go back to a more normal production pattern and recover from two consecutive years of bad weather, which will allow regaining its market share. Vietnam is expected to expand exports over the next decade, supported by increased domestic surplus and strategic imports from Cambodia and other regional suppliers.

For the U.S., total exports over the next decade are expected to increase by 187 tmt, reaching 3.2 mmt in 2029–2031, while imports to increase by 105 tmt, totaling 1.2 mmt in 2029–2031 (Fig. 3). For reference purposes, detailed U.S. rice supply and use data are presented in English units and on a 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). Imports from India surged in 2021, and also from other less traditional origins such as Pakistan and Cambodia. Nigeria's rice imports will more than

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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.

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 consideration.

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.

double to 3.7 mmt a year by 2029–2031, while the Philippines is projected to expand imports to 3.1 mmt a year by 2029–2031.

Global rice stocks are projected to grow significantly by 25.9 mmt or 14.3% over the next decade relative to the 2018–2020 level (Table 2; Fig. 2). Relative to consumption, global rice stocks are projected to increase slightly over the next decade, with the stock-to-consumption ratio projected to increase from 36.9% annual average in the period 2018–2020 to 38.7% in 2029–2031. In other words, annual ending stocks in 2029–2031 will be enough to feed the global population for 4½ months.

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

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Literature Cited

USDA-ERS. 2022. United States Department of Agriculture, Economic Research Service. Rice Outlook. RCS-22B. Accessed 11 February 2022. Available at: https://www.ers.usda.gov/webdocs/outlooks/103260/rcs-22b.pdf?v=1847.2

USDA-FAS. 2022a. United States Department of Agriculture, Foreign Agricultural Service. World Agricultural Supply and Demand Estimates. WASDE-620. Accessed 12 January 2022. Available at: https://downloads.usda.library.cornell.edu/usda-esmis/files/3t945q76s/pv63h1937/n009x4613/wasde0122.pdf

USDA-FAS. 2022b. United States Department of Agriculture, Foreign Agricultural Service. Production, Supply, and Distribution (PSD) Online. Accessed 14 January 2022. Available at: https://apps.fas.usda.gov/psdonline/app/index.html#/app/advQuery

Wailes, E.J. and E.C. Chavez. 2011. 2011 Updated Arkansas Global Rice Model. University of Arkansas System Division of Agriculture's Department of Agricultural Economics and Agribusiness, Division of Agriculture Staff Paper 2011-01. Accessed 11 February 2022. Available at: https://agecon-search.umn.edu/record/102650

Table 1. Projected changes in world rice total trade by country (in 1,000 metric tons) with U.S. and global prices.

Country	2018–2020 Average	2029–2031 Average	Change	Country	2018–2020 Average	2029–2031 Average	Change
Exporters							
India	14,368	21,779	7,411	EU 28	492	491	-0.3
Thailand	6,389	9,196	2,807	Australia	84	378	294
Vietnam	6,333	7,581	1,249	Peru	75	22	-53
Pakistan	4,063	4,362	299	Guinea	77	30	-47
United States	2,977	3,164	187	Cote d'Ivoire	58	25	-33
Myanmar	2,317	3,076	760	Egypt	15	20	5
China	2,531	2,670	139	Japan	60	70	10
Cambodia	1,517	1,893	376	Turkey	213	220	7
Brazil	949	900	-49	Tanzania	30	30	0
Uruguay	824	914	90	Venezuela	0	0	0
Paraguay	704	927	223	Senegal	30	60	30
Guyana	477	633	156	Sri Lanka	7	5	-2
Argentina	354	472	118	Laos	-117	-50	67
				Rest of world	1,124	1,430	306
Total Exports					**45,950**	**60,299**	**14,349**
Importers							
China	3,433	4,032	599	Canada	439	461	22
Nigeria	1,733	3,716	1,983	Sierra Leone	400	338	-62
Ecowas 7[a]	2,183	4,285	2,102	Egypt	447	766	319
Philippines	2,750	3,112	362	Liberia	323	476	153
EU 28	1,863	2,524	661	Sri Lanka	19	-109	-129
Cote d'Ivoire	1,227	2,333	1,107	Hong Kong	307	385	79
Saudi Arabia	1,413	1,758	345	Peru	280	475	196
Iran	1,117	1,801	685	Singapore	362	318	-44
Bangladesh	607	1,123	516	Turkey	461	373	-88
Iraq	1,188	1,540	352	Tanzania	187	315	128
Senegal	1,100	1,817	717	Thailand	233	225	-8
South Africa	1,007	1,104	97	Mali	300	1,305	1,005
Indonesia	583	926	343	Australia	230	175	-55
Malaysia	1,107	957	-150	Chile	171	174	3
United States	1,063	1,168	105	Costa Rica	149	128	-21
Mexico	795	923	128	Colombia	187	200	12
Ghana	920	1,389	469	Honduras	138	169	31
Guinea	690	786	96	Uganda	80	249	169
Japan	674	682	8	Taiwan	109	100	-9
Brazil	777	615	-162	Guatemala	113	163	50
Kenya	598	1,232	633	Nicaragua	108	103	-5
Mozambique	607	1,088	482	Panama	77	118	41
Cameroon	558	1,015	457	Brunei	24	35	11
Cuba	454	553	98	Rwanda	40	256	216
Haiti	498	609	111	Dominican Republic	28	46	18
Vietnam	900	500	-400	Malawi	15	59	44
Venezuela	535	726	192	Zambia	10	17	7
South Korea	391	411	20	Pakistan	7	7	0
Madagascar	434	1,216	782	Paraguay	2	2	0
				Rest of world	9,499	9,028	-471
Total Imports					**45,950**	**60,299**	**14,349**
Prices (US$/metric ton)							
Long grain International Rice Reference Price (Thailand 100% B)					449	486	37
U.S. No. 2 long grain FOB[b] Gulf Ports					605	653	48
U.S. No. 1 medium grain FOB California					880	1,039	158

[a] Includes the following seven members of the Economic Community of West African States: Benin, Burkina, Gambia, Guinea-Bissau, Niger, Togo, and Cape Verde.

[b] FOB = free on board.

Table 2. Projected world rice supply and utilization (in 1,000 metric tons) and macroeconomic data.

Variable	2018–2020 Average	2029–2031 Average	Change
Area Harvested (1000 ha)	163,288	164,221	933
Yield (kg/ha)	3.07	3.25	0.2
Production	501,294	533,162	31,868
Beginning Stocks	174,001	206,880	32,879
Domestic Supply	675,295	740,042	64,747
Consumption	492,039	536,089	44,050
Ending Stocks	181,580	207,500	25,920
Domestic Use	673,619	743,589	69,970
Total Trade	45,950	60,299	14,349
Stocks-to-consumption Ratio (%)	36.9	38.7	1.8
Annual population growth (%)	1.1	0.8	-0.3
Annual real GDP[a] growth (%)	0.8	2.9	2.0

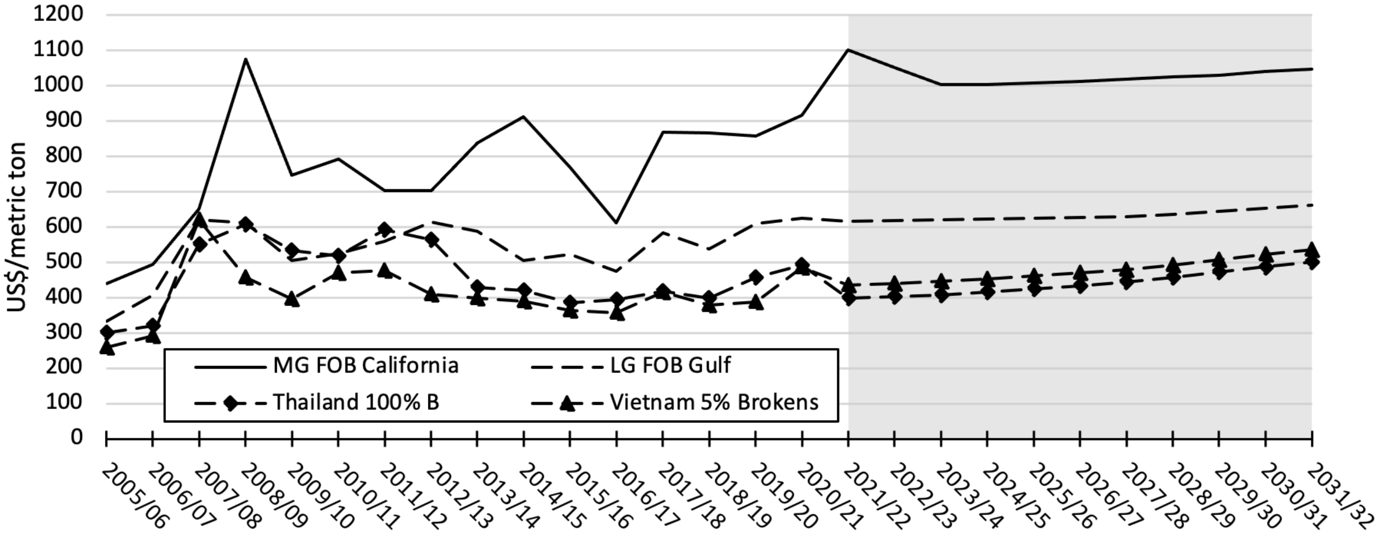
[a] GDP = gross domestic product.

Table 3. United States rice supply and utilization (in paddy basis, million hundredweight unless specified otherwise), prices, and macroeconomic data.

Variable	2018–2020 Average	2029–2031	Change
Yield (lb/ac, paddy basis)	7,594.7	8,137.4	542.7
Total Harvested Area (1000 ac)	1,129.3	1,116.4	-13.0
Supply	278.4	296.5	18.1
Production	212.2	224.5	12.3
Beginning Stocks	32.8	35.2	2.4
Imports	33.5	36.8	3.3
Domestic Use	147.1	160.8	13.7
Food	124.8	127.5	2.7
Seed	2.1	2.3	0.1
Brewing	19.0	20.5	1.6
Residual	1.2	10.5	9.3
Exports	93.8	99.7	5.9
Total Use	240.9	260.5	19.6
Ending Stocks	37.2	36.0	-1.2
Stocks-to-Use Ratio	15.4	13.8	-1.6
	Market Prices (US$/cwt)		
Loan Rate	6.50	7.00	0.50
Season Average Farm Price	13.4	15.2	1.76
Long-Grain Farm Price	11.8	13.6	1.77
Medium-Grain Farm Price	18.5	19.8	1.32
Japonica Farm Price	21.2	22.6	1.44
Southern Medium-Grain Farm Price	12.3	13.7	1.34
	Reference Prices (US$/cwt)		
Long-Grain Farm Price	14.0	14.0	0.0
Southern Medium-Grain Farm Price	14.0	14.0	0.0
Japonica	16.1	16.1	0.0
Long-Grain Export Price, FOB[a] Houston (U.S. No. 2)	26.8	29.0	2.2
Medium-Grain Price, FOB[a] CA (U.S. No. 2)	39.9	47.1	7.2
Average World Price (US$/cwt)	10.0	11.5	1.5
Per Capita Use (lb/capita)	44.5	46.3	1.8
Population growth (%)	0.3	0.5	0.2
Real GDP[b] Growth (%)	0.6	2.2	1.6

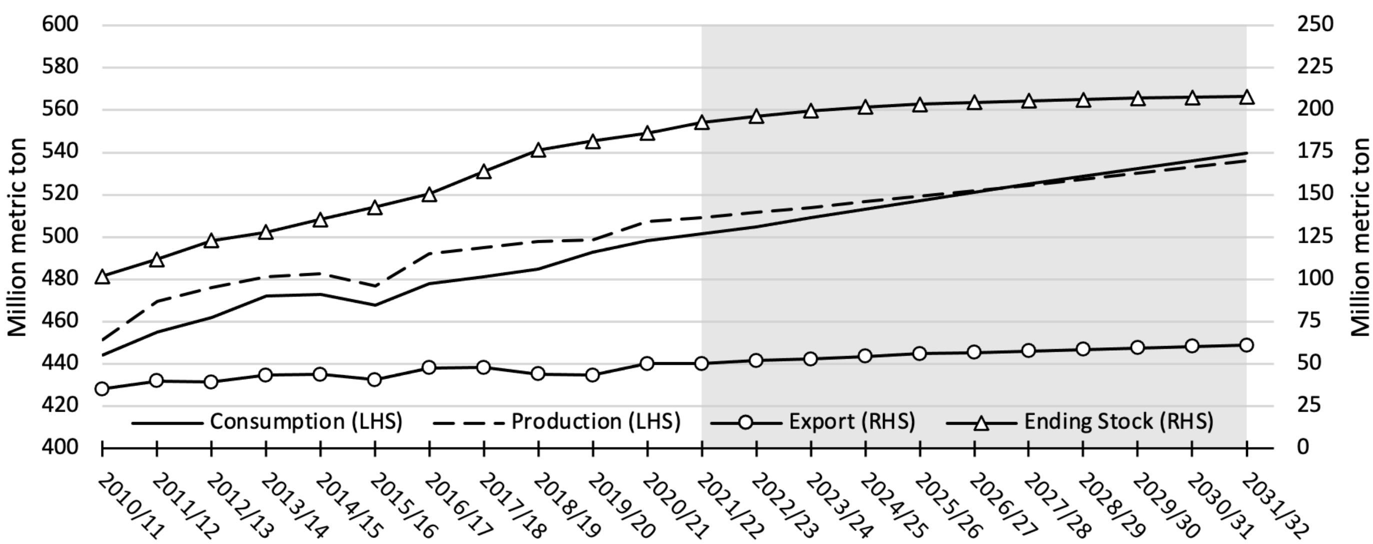
[a] FOB = free on board.

[b] GDP = gross domestic product.



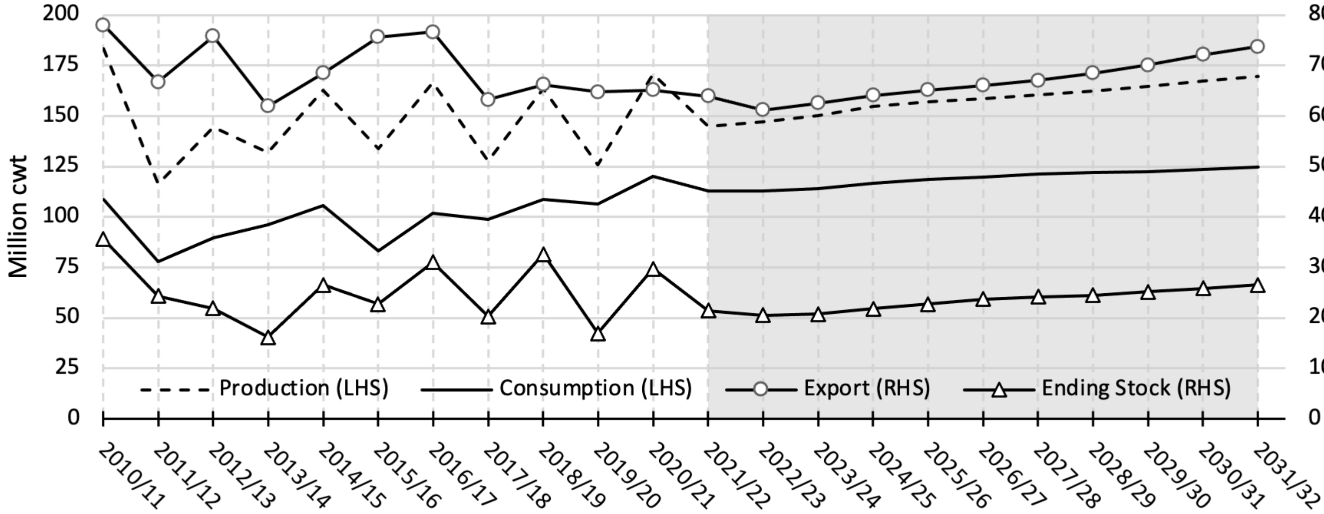
Source: USDA-ERS Rice Outlook, February 2022. AGRM projections January 2022.

Fig. 1. Annual Historical and Projected U.S. and Asian milled rice prices, US$ per metric ton, 2005–2031. The shaded area represents the projected period



Source: USDA-ERS Rice Outlook, February 2022. AGRM projections January 2022.

Fig. 2. (left hand side) Global rice production, consumption, (right hand side) trade, and ending stocks, 2005–2031. The shaded area represents the projected period.



Source: USDA-ERS Rice Outlook, February 2022. AGRM projections January 2022.

Fig. 3. (left hand side) United States rice production, consumption, (right hand side) trade, and ending stocks, 2005–2031. The shaded area represents the projected period.

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 the University of Arkansas System Division of Agriculture 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 decisions 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 are extended by production economics analysis to investigate factors impacting farm profitability.

Introduction

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

Procedures

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

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

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

Results and Discussion

The 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 Department of Crop, Soil, and Environmental Sciences. Actual production practices vary greatly among individual farms due to management preferences and between production years

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due to climatic 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 the revenue and expenses of the 2022 rice enterprise budgets. Costs are presented on a per-acre basis and with an assumed yield of 170 bushels for conventional varieties and 190 bushels for hybrids. The price received for 2022 was set at $6.25/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 $944.81 per acre (conventional seed) to $1042.67 per acre (FullPage 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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Literature Cited

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

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

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

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

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

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

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

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)	6.25	6.25	6.25	6.25	6.25
Grower Share, %	100%	100%	100%	100%	100%
Crop Revenue	**1062.50**	**1062.50**	**1187.50**	**1187.50**	**1062.50**
Operating Expenses					
Input Costs	684.89	619.57	703.50	678.30	689.91
Other Operating Expenses	108.45	107.00	108.86	108.30	108.56
Total Operating Expenses	793.34	726.57	812.36	786.60	798.47
Post-harvest Expenses	102.60	102.60	114.67	114.67	102.60
Net Operating Expenses	**895.94**	**829.17**	**927.03**	**901.27**	**901.07**
Cash Land Rent	0.00	0.00	0.00	0.00	0.00
Returns to Operating Expenses	**166.56**	**233.33**	**260.47**	**286.23**	**161.43**
Fixed Costs	115.64	115.64	115.64	115.64	115.64
Total Specified Expenses[a]	**1011.58**	**944.81**	**1042.67**	**1016.91**	**1016.71**
Returns to Specified Expenses[b]	**50.92**	**117.69**	**144.83**	**170.59**	**45.79**
Operating Expenses/yield unit	5.27	4.88	4.88	4.74	5.30
Total Expenses[b]/yield unit	5.95	5.56	5.49	5.35	5.98
Land Expense/acre	0.00	0.00	0.00	0.00	0.00
Land Expense/yield unit	0.00	0.00	0.00	0.00	0.00
Operating & Land Expenses/yield unit	5.27	4.88	4.88	4.74	5.30
Total Cost/yield unit, including land	5.95	5.56	5.49	5.35	5.98

[a] Share rent and cash land rent are deducted from crop revenue.

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

A Safety-First Profit and Risk Analysis of Alternative Rice Planting Windows and Long-Grain Rice Cultivar Types in East-Central Arkansas

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Abstract

The timing of rice planting can greatly affect the profitability of rice production. Planting too early or too late can result in significant yield reductions and can, thus, reduce economic returns. Earlier studies primarily focused on the impacts of planting timing on public pure-line rice cultivars and did not evaluate the impacts of planting timing on rice profitability. The effects of planting timing on rice return variability have also not been considered. This study uses a safety-first approach to incorporate risk considerations into the economic analysis of rice planting and timing decisions in east-central Arkansas. Expected net returns and lower confidence limits on returns are evaluated for risk-neutral and risk-averse rice producers, respectively. The results indicate that all rice cultivar types produce the largest expected net returns and the largest lower confidence limits when planted early (11 March–14 April). Hybrid rice cultivars result in the largest expected net returns and the largest lower confidence limits, while herbicide-tolerant non-hybrid cultivars result in the lowest expected net returns and the lowest lower confidence limits across all planting windows examined in the study.

Introduction

Planting rice in an appropriate period of time is critical for profitable rice production. Planting rice too early as well as too late may result in significant yield loss. Planting decisions depend not only on the planting date but also on the types of rice cultivars planted. Planting decisions are also strongly impacted by weather. Rice growers may not be able to plant at a desirable date as weather, particularly excessive precipitation, can become a major factor (Watkins and Gautam, 2021).

Earlier studies (Blanche and Linscombe, 2009; Gravois and Helms, 1998; Sha and Linscombe, 2007; Slaton et al., 2003) evaluated the impacts of planting date on rice grain yields and/or milling quality and did not consider impacts on rice profitability. The earlier studies also focused primarily on public pure-line cultivars. Rice producers currently have several different rice cultivar types to choose from, ranging from public pure-lines, proprietary herbicide-tolerant cultivars, and proprietary hybrids, both with and without herbicide tolerance.

Gautam et al. (2021) did evaluate gross monetary returns (price × yield) by planting date and cultivar type and found planting rice in the latter part of March or the first two weeks of April tends to generate larger gross returns relative to planting rice at later dates. However, Gautam et al. did not take production costs (variable and fixed expenses) into consideration and did not evaluate the impacts of return variability on rice profitability. The main objective of this study is to evaluate the impact of rice planting date and cultivar type on rice net returns (gross returns less variable and fixed expenses) both with and without return variability being considered.

Procedures

Data for this study comes from Degree-Day 50 (DD50) rice cultivar thermal unit threshold studies conducted annually by the University of Arkansas System Division of Agriculture (UADA) for the purpose of maintaining the DD50 computer management aid used by Arkansas rice producers (Clayton et al., 2021). Grain yields, whole kernel milling yields, and total milling yields were collected by planting date, cultivar, and year for the period 2012 through 2021. All data come from studies conducted at the UADA Rice Research and Extension Center (RREC) near Stuttgart, Arkansas. All data also focus exclusively on long long-grain cultivars.

Data from the DD50 studies were used to calculate net returns (gross returns less variable and fixed expenses) by planting date, rice cultivar, and year. Net returns were standardized to contemporary 2019–2021 average values for comparison across all 10 years. Gross returns were calculated as the product of rice grain yields and milling adjusted rice prices. Milling adjusted rice prices were calculated based on whole kernel and total rice milling yields recorded by cultivar and planting date in the DD50 studies, the 3-year average U.S. long long-grain harvest price (August through October) of $5.55/bu. obtained from the USDA National Agricultural Statistics Service (USDA-NASS, 2022a), and 3-year average long long-grain loan values for whole and broken kernels ($4.79/bu. and $2.90/bu., respectively) obtained from the USDA Farm Service Agency (USDA-FSA, 2022) for the period 2019–2021. Milling adjusted long long-grain prices were calculated based on a standard milling yield of 55/70.

Production expenses by cultivar type were calculated based on 3-year average variable and fixed expenses by rice cultivar type obtained from UADA crop enterprise budgets for the period 2019–2021 (UADA-CES, 2022). Three cultivar types were evaluated in the study: 1) long long-grain pure-lines; 2) long long-grain herbicide tolerant non-hybrid proprietary lines (herbicide-tolerant lines); and 3) long long-grain hybrid proprietary lines (hybrid lines). Hybrid lines included both herbicide non-tolerant hybrids and herbicide-tolerant hybrids.

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Planting dates in the DD50 studies were grouped into planting windows based on the percent of rice acres planted on a weekly basis by month and year as reported by the USDA National Agricultural Statistics Service, Arkansas Field Office (USDA-NASS, 2022b). Three planting windows were created based on these historical data: 1) early planting window (11 March–14 April); 2) middle planting window (15 April–14 May); and 3) late planting window (15 May–30 June).

A safety-first approach is used in this study to incorporate risk considerations into the economic analysis of rice planting timing decisions (Musser et al., 1981). The safety-first criterion assumes a producer wants to maximize profits subject to some probability that profits remain above some target return. For example, a risk-averse producer may desire that net returns for a particular crop enterprise not fall below \$250/acre for more than 1 out of 4 years. This is equivalent to specifying that the lower bound of a 75% confidence interval be at least \$250/acre.

The lower confidence limit of net returns (LCL_i) can be calculated as follows:

$$LCL_i = E_i - K\sigma_i$$

where E_i = the expected net return for activity i; σ_i = the standard deviation of net returns for activity i, and K = the number of standard deviations required to impose the desired probability that net return will be greater than LCL_i. Assuming that net returns are distributed normally, the value for K is 0.675 for a 75% lower confidence limit (net returns fall below the LCL_i in 1 out of 4 years), 0.845 (net returns fall below the LCL_i in 1 out of 5 years), and 1.285 (net returns fall below the LCL_i in 1 out of 10 years).

Results and Discussion

Safety-first risk analysis results of long-grain rice cultivar types by planting window are presented for the RREC in Table 1, and expected net returns and lower confidence limits by planting date are presented visually by rice cultivar type in Figs. 1–4. Risk neutrality is assumed when return variability is not a consideration (σ_i = 0 in the LCL_i equation). In this instance, a risk-neutral rice producer would prefer the planting window for each rice cultivar type that provides the largest expected net return. The early planting window would be preferred by risk-neutral rice producers, as expected returns by rice cultivar type are largest for the early planting window relative to the middle and late planting windows. Risk-averse rice producers are concerned with return variability and prefer a planting window for each rice cultivar that results in the largest LCLs. Risk-averse rice producers would also prefer to plant each rice cultivar type in the early planting window, as is evident by the larger LCLs for the early planting window relative to the middle and late planting windows (Table 1; Figs. 1–4). However, planting rice early may not be feasible due to excessive precipitation during the growing season (Watkins and Gautam, 2022). Therefore, rice producers need to examine the return potential for the middle planting window also, as planting earlier may not always be an available option.

The choice of rice cultivar type to plant within each planting window also impacts the profitability and return variability of rice production. Expected net returns and LCLs are larger for hybrid lines across all planting windows (Table 1, Fig. 3), implying hybrid lines would be preferred over other long-grain rice lines by both risk-neutral and risk-averse rice producers. The difference in expected net returns between the early planting window and the middle planting window is also smaller for hybrid lines relative to other long-grain rice lines (Fig. 3). Herbicide-tolerant lines exhibit the lowest returns across all planting windows (Fig. 2). Herbicide-tolerant lines also appear to be more sensitive to planting timing than other long-grain rice lines. Drops in both expected net returns and LCLs are more significant for herbicide-tolerant lines when moving from early to middle to late planting windows (Fig. 2).

Practical Applications

The results of this study point out that both planting timing and rice cultivar type affect the profitability and the return variability of rice production. Planting early when feasible (11 March–14 April) tends to result in the largest expected returns and the lowest return variability. However, planting early may not be feasible due to weather constraints. Hybrid lines tend to perform best in terms of net returns across all planting windows, and hybrid lines, if seed is available, would be more favorable than other long-grain rice lines when rice producers must plant rice later than normal due to weather. Herbicide-tolerant non-hybrid lines tend to result in the lowest expected returns across planting windows, particularly when planted in the middle (15 April–14 May) and late (15 May–30 June) planting windows evaluated in this study. Herbicide-tolerant non-hybrid lines perform best in terms of profitability when planted early, and other cultivar types should be considered when planting early is not feasible, such as hybrids lines or long-grain pure-lines. The results of this study should be placed in the proper context, since the data for this study comes from the RREC near Stuttgart, Ark. The results of this study are, thus, more applicable to east-central Arkansas, or more specifically the Grand Prairie region of Arkansas.

Acknowledgments

This research was supported by 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.

Literature Cited

Blanche, S.B. and S.D. Linscombe. 2009. Stability of rice grain and whole kernel milling yield as affected by cultivar and date of planting. Agron. J. 101:522-528.

Clayton, T.L., E. Castaneda-Gonzalez, J.T. Hardke, D.L. Frizzell, K.F. Hale, T.D. Frizzell, L.R. Amos, A. Ablao, K.A.K. Moldenhauer, and X. Sha. 2021. 2020 Degree-Day 50 (DD50) thermal unit thresholds for new rice cultivars and seeding date studies. *In*: J. Hardke, X. Sha, and N. Bateman (eds.) B.R. Wells Arkansas Rice Research Studies 2020. Arkansas Agricultural Experiment Station Research Series 676:200-209. Fayetteville.

Gautam, T.K., K.B. Watkins, and J.T. Hardke. 2021. Estimating the impact of rice planting date and cultivar type on rice economic returns in Arkansas. *In*: J. Hardke, X. Sha, and N. Bateman (eds.) B.R. Wells Arkansas Rice Research Studies 2020. Arkansas Agricultural Experiment Station Research Series 676:309-312. Fayetteville.

Gravois, K.A. and R.S. Helms. 1998. Seeding date effects on rough rice yield and head rice and selection for stability. Euphytica 102:151-159.

Musser, W.N., J. Ohannesian, and F.J. Benson. 1981. A safety first model of risk management for use in extension programs. North Central J. Agric. Econ. 3(1):41-46.

Sha, X.Y and S.D. Linscombe. 2007. Planting date affects grain and milling yields of water-seeded Clearfield rice. Agron. J., 99:1143-1150.

Slaton, N.A., S.D. Linscombe, R.J. Norman, and E.E. Gbur, Jr. 2003. Seeding date effect on rice grain yields in Arkansas and Louisiana. Agron. J. 95:218-223.

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

USDA-NASS. 2022a. United States Department of Agriculture, National Agricultural Statistics Service. Quick Stats (Searchable Database). Accessed 18 January 2022. Available at: https://quickstats.nass.usda.gov/

USDA-NASS. 2022b. United States Department of Agriculture, National Agricultural Statistics Service, Arkansas Field Office. Crop Progress & Condition, 2012–2021. Accessed 3 January 2022. Available at: https://www.nass.usda.gov/Statistics_by_State/Arkansas/Publications/Crop_Progress_&_Condition/index.php

USDA-FSA. 2022. United States Department of Agriculture, Farm Service Agency. Rice Program. Accessed 18 January 2022. Available at: https://www.fsa.usda.gov/programs-and-services/price-support/commodity-loans/non-recourse-loans/rice-program/index

Watkins, K.B., and T.K. Gautam. 2021. An overview of rice prevented planting acres in Arkansas, 2011 to 2020. *In*: J. Hardke, X. Sha, and N. Bateman (eds.) B.R. Wells Arkansas Rice Research Studies 2020. Arkansas Agricultural Experiment Station Research Series 676:317-321. Fayetteville.

Table 1. Safety-first risk analysis of long-grain rice cultivar types by planting window, University of Arkansas System Division of Agriculture's Rice Research and Extension Center near Stuttgart, Arkansas, 2012–2021.

Planting Window[a]	Mean	SD[b]	CV[b]	75% LCL[c]	80% LCL	90% LCL
	($/ac)	($/ac)		($/ac)	($/ac)	($/ac)
			Long-Grain Pure-Lines			
Early Planting	436	140	32	341	317	256
Middle Planting	351	139	40	257	234	172
Late Planting	262	97	37	196	180	137
			Herbicide-Tolerant Lines (Non-Hybrid)			
Early Planting	351	120	34	270	250	197
Middle Planting	228	131	57	140	118	60
Late Planting	119	91	77	58	42	2
			Hybrid Lines (Herbicide Non-Tolerant and Herbicide-Tolerant)			
Early Planting	498	109	22	424	405	357
Middle Planting	467	118	25	388	368	316
Late Planting	359	93	26	296	280	239
			All Long-Grain Lines			
Early Planting	429	137	32	336	313	253
Middle Planting	349	160	46	241	214	144
Late Planting	248	135	54	157	134	75

[a] Early planting = 11 March–14 April; middle planting = 15 April–14 May; late planting = 15 May–30 June.

[b] SD = standard deviation; CV = coefficient of variation.

[c] LCL = lower confidence limit.

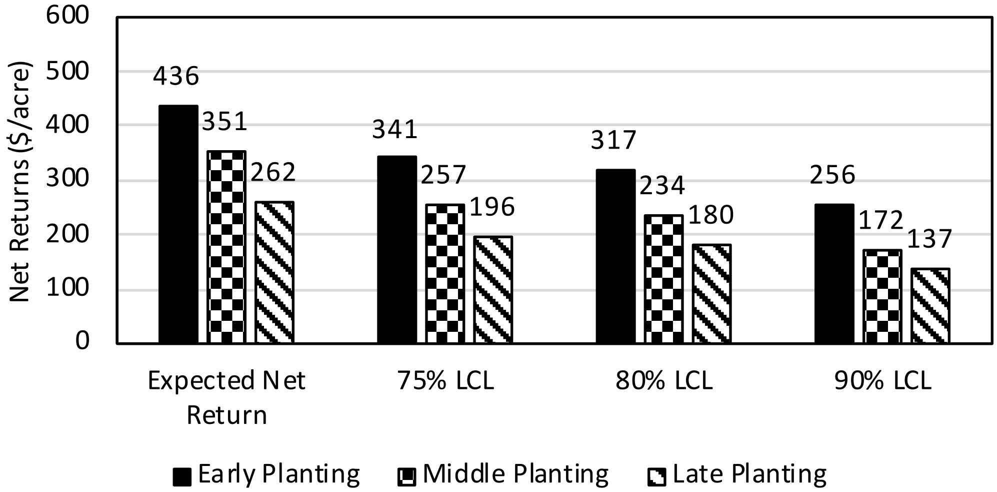

Fig. 1. Long-grain pure-lines: expected net returns and lower confidence limits (LCLs) by planting window (early planting = 11 March–14 April; middle planting = 15 April–14 May; late planting = 15 May–30 June), University of Arkansas System Division of Agriculture's Rice Research and Extension Center near Stuttgart, Arkansas, 2012–2021.

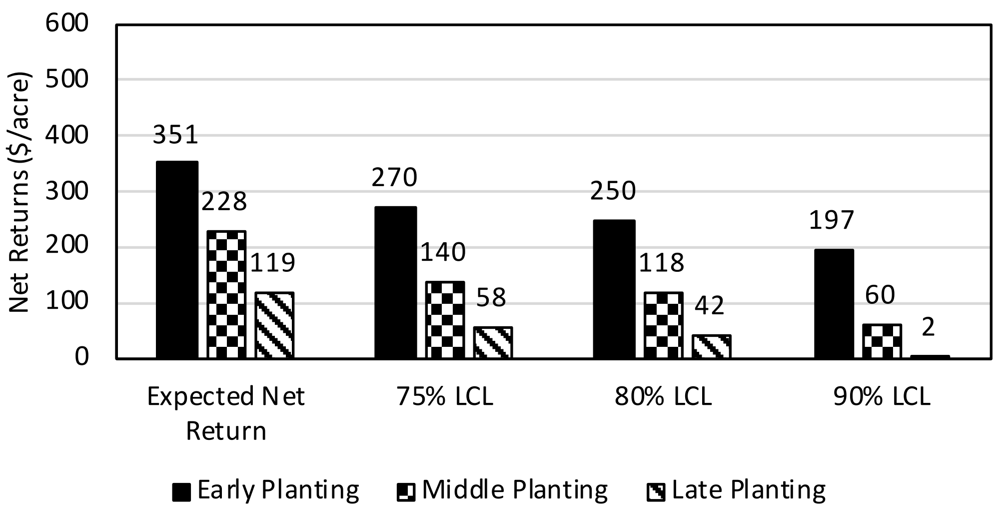

Fig. 2. Herbicide-tolerant lines (non-hybrid): expected net returns and lower confidence limits (LCLs) by planting window (early planting = 11 March–14 April; middle planting = 15 April–14 May; late planting = 15 May–30 June), University of Arkansas System Division of Agriculture's Rice Research and Extension Center near Stuttgart, Arkansas, 2012–2021.

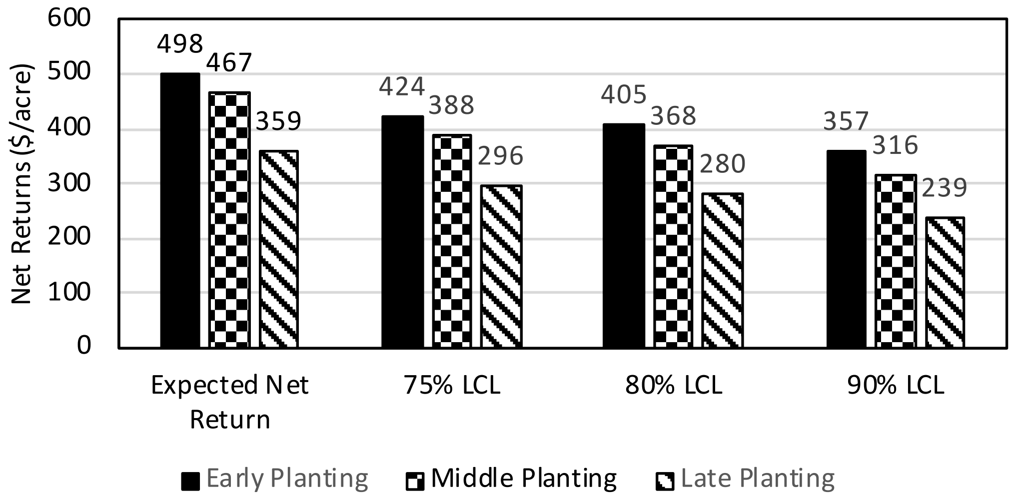

Fig. 3. Hybrid lines (both herbicide non-tolerant and herbicide-tolerant): expected net returns and lower confidence limits (LCLs) by planting window (early planting = 11 March–14 April; middle planting = 15 April–14 May; late planting = 15 May–30 June), University of Arkansas System Division of Agriculture's Rice Research and Extension Center near Stuttgart, Arkansas, 2012–2021.

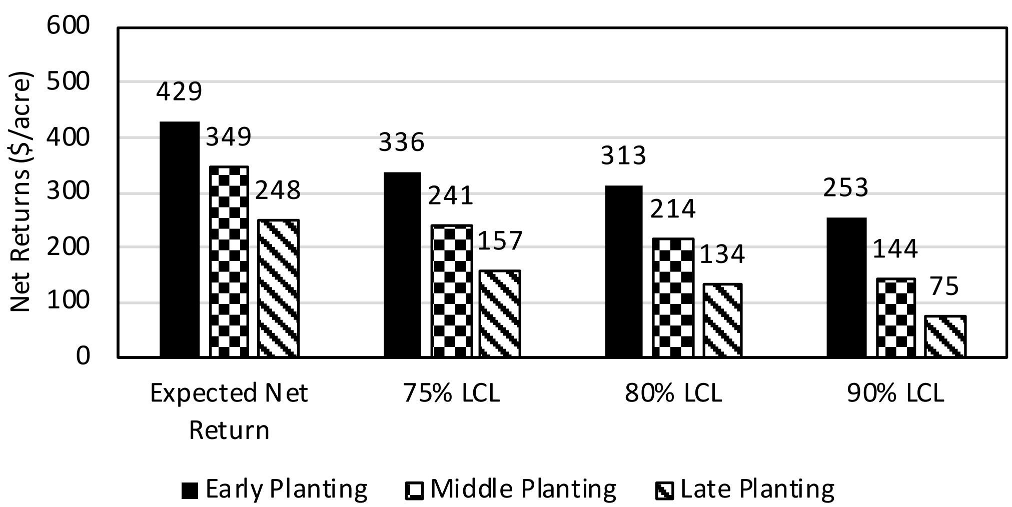

Fig. 4. All long-grain lines: expected net returns and lower confidence limits (LCLs) by planting window (early planting = 11 March–14 April; middle planting = 15 April–14 May; late planting = 15 May–30 June), University of Arkansas System Division of Agriculture's Rice Research and Extension Center near Stuttgart, Arkansas, 2012–2021.

Expected Monetary Payoffs for Planting Alternative Rice Cultivar Types in Different Planting Windows During Dry, Wet, and Normal Growing Seasons

K.B. Watkins,[1] T.K. Gautam,[1] and J.T. Hardke[2]

Abstract

The timing of rice planting, the type of cultivar planted, and weather can greatly affect the profitability of rice production. Earlier studies focused on the impacts of rice planting timing on grain yields and/or milling yields and concentrated almost exclusively on public pure-line rice cultivars. The earlier studies also did not evaluate the impacts of planting timing on rice profitability. The impacts of weather outcomes on the profitability of rice planting timing have also not been evaluated. This study uses a payoff matrix approach to evaluate the economic impacts of different planting windows and cultivar types on rice profitability during dry, wet, and normal growing seasons. The results indicate that expected monetary payoffs are greatest in dry and normal growing seasons when all rice cultivar types are planted early (11 March–14 April) but are greatest in wet growing seasons for long-grain pure-lines and hybrids when planted in the middle planting window (15 April–14 May). Monetary payoffs by planting window are smallest for herbicide-tolerant non-hybrids relative to all other rice cultivar types regardless of the weather outcome faced during the growing season.

Introduction

Planting rice in an appropriate period of time is critical for profitable rice production. Planting rice too early as well as too late may result in significant yield loss. Planting decisions depend not only on the planting date but also on the types of rice cultivars planted. Planting decisions are also strongly impacted by weather. Rice growers may not be able to plant at a desirable date as weather, particularly excessive precipitation, can become a major factor (Watkins and Gautam, 2021).

Earlier studies (Blanche and Linscombe, 2009; Gravois and Helms, 1998; Sha and Linscombe, 2007; Slaton et al., 2003) evaluated the impacts of planting date on rice grain yields and/or milling quality but did not evaluate the impacts of rice planting date on monetary returns. These studies also focused primarily on public pure-lines. Rice producers currently have several different rice cultivar types to choose from, ranging from public pure- lines, proprietary herbicide-tolerant cultivars, and proprietary hybrids both with and without herbicide tolerance. The impacts of weather outcomes on the profitability of rice planting timing have also not been considered.

Gautam et al. (2021) evaluated gross monetary returns (price × yield) by planting date and cultivar type and found planting rice in the latter part of March or the first 2 weeks of April tends to generate larger gross returns relative to planting rice at later dates. However, this study did not take production costs (variable and fixed expenses) into consideration. This study also did not address how weather outcomes affect the profitability of rice planting timing. The main objective of this study is to evaluate the impact of rice planting date and cultivar type on rice net returns (gross returns less variable and fixed expenses) during dry, wet, and normal rice-growing seasons.

Procedures

Data for this study come from Degree-Day 50 (DD50) rice cultivar thermal unit threshold studies conducted annually by the University of Arkansas System Division of Agriculture (UADA) for the purpose of maintaining the DD50 computer management aid used by Arkansas rice producers (Clayton et al., 2021). Grain yields, whole kernel milling yields, and total milling yields were collected by planting date, cultivar, and year for the period 2012 through 2021. All data come from studies conducted at the UADA Rice Research and Extension Center (RREC) near Stuttgart, Ark., and focus exclusively on long-grain cultivars.

Data from the DD50 studies were used to calculate net returns by planting date, rice cultivar, and year. Net returns were calculated as gross returns less variable and fixed expenses and were standardized to contemporary 2019–2021 average values for comparison across all 10 years. Gross returns were calculated as the product of rice grain yields and milling adjusted rice prices. Milling adjusted rice prices were calculated based on whole kernel and total rice milling yields recorded by cultivar and planting date in the DD50 studies, the 3-year average U.S. long-grain harvest price (August through October) of \$5.55/bu. obtained from the USDA National Agricultural Statistics Service (USDA-NASS, 2022a), and 3-year average long-grain loan values for whole and broken kernels (\$4.79/bu. and \$2.90/bu., respectively) obtained from the USDA Farm Service Agency (USDA-FSA, 2022) for the period 2019–2021. Milling adjusted long-grain prices were calculated based on a standard milling yield of 55/70.

Production expenses by cultivar type were calculated based on 3-year average variable and fixed expenses by rice cultivar type obtained from UADA crop enterprise budgets for the period 2019–2021 (UADA-CES, 2022). Three cultivar types were evaluated in

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the study: 1) long-grain pure-lines; 2) long-grain herbicide-tolerant non-hybrid proprietary lines (herbicide-tolerant lines); and 3) long-grain hybrid proprietary lines (hybrid lines). Hybrid lines included both herbicide non-tolerant hybrids and herbicide-tolerant hybrids.

Planting dates in the DD50 studies were grouped into planting windows based on the percent of rice acres planted on a weekly basis by month and year as reported by the USDA National Agricultural Statistics Service, Arkansas Field Office (USDA-NASS, 2022b). Three planting windows were created based on these historical data: 1) early planting window (11 March–14 April); 2. middle planting window (15 April–14 May); and 3) late planting window (15 May–30 June). A payoff matrix approach was used to evaluate the economic impacts of different planting windows and cultivar types on rice profitability given different weather outcomes during the growing season (Walker et al. 1984). A payoff matrix shows the payoffs (expected net returns) associated with choosing specific actions (planting different rice cultivar types in different planting windows) given possible states of nature (weather outcomes) for which decision-makers have little or no control.

Results and Discussion

Annual percentages of Arkansas rice area planted by planting window are presented for 2012 through 2021 in Table 1. On average, 53% of the rice area was planted in the middle planting window, 30% was planted in the early planting window, and 17% was planted in the late planting window during the 10-year period. However, none of the 10 years examined fit the average, indicating the average is not a good representation of the amount of area planted by the planting window for any of the 10 years due to varying weather conditions within each year. A more accurate depiction would be to group each year based on its weather outcome.

Three weather outcomes were defined for this study based on historical data presented in Table 1: 1) a wet growing season, 2) a dry growing season, and 3) a normal growing season. A wet growing season is defined as one when a significant rice area is planted in the late planting window due to large precipitation levels. The years 2013, 2019, and 2020 may be defined as wet growing seasons. A dry growing season is defined as one when a significant amount of rice area is planted in the early planting window due to dry, moderate conditions. The years 2012, 2016, and 2017 may be defined as dry growing seasons. Finally, a normal growing season is defined as one when the rice planted area is heavily weighted in the middle planting window and weighted lower in the early and late planting windows. The years 2014, 2015, 2018, and 2021 may be defined as normal growing seasons. Net returns by rice cultivar type and planting window were averaged across dry, wet, and normal growing seasons (years) to determine expected monetary payoffs associated with planting rice in different planting windows and growing seasons.

The expected monetary payoffs for a dry growing season by cultivar type and planting window are presented in Fig. 1. The early planting window (11 March–14 April) produces the largest monetary payoff for all long-grain cultivar types, with hybrid lines having the biggest payoff ($502/acre) followed by long-grain pure-lines ($459/acre) and herbicide-tolerant lines ($331/acre). Payoffs progressively drop when planting in the middle and late planting windows. The weighted net return for each cultivar type in Fig. 1 is calculated as the monetary payoff for each cultivar type weighted by the historical percentage of acres planted in each planting window. Weighted net returns for each cultivar type fall between the payoffs associated with the early and middle planting windows, reflecting a greater likelihood of planting rice in either the early or middle planting windows during a dry growing season.

The expected monetary payoffs for a wet growing season by cultivar type and planting window are presented in Fig. 2. A striking feature in Fig. 2 is the middle planting window (15 April–14 May), which generally has the largest net return payoffs. This occurs across all long-grain lines on average ($483/acre), for long-grain pure-lines ($474/acre) and for hybrid lines ($590/acre). The herbicide-tolerant lines are the exception to the rule, having the biggest payoff ($364/acre) occurring in the early planting window (11 March–14 April). Weighted net returns for each cultivar type fall between the payoffs of the middle and late planting windows, reflecting a higher likelihood of planting rice in either the middle or the late planting window during a wet growing season.

The expected monetary payoffs for a normal growing season by cultivar type and planting window are presented in Fig. 3. Payoffs for a normal growing season mirror those for a dry growing season, following the same pattern, namely larger payoffs in the early planting window, and progressively smaller payoffs when moving to the middle and late planting windows. In all planting windows, payoffs are greatest for hybrid lines and smallest for herbicide-tolerant lines.

Weighted net returns for each cultivar type are slightly larger than the payoffs associated with the middle planting window, reflecting a greater likelihood of planting rice in the middle planting window during a normal growing season.

Practical Applications

This study demonstrates that weather in the growing season not only dictates when rice can be planted but also has a significant impact on the monetary payoffs associated with the timing of rice planting. Monetary payoffs in dry and normal growing seasons tend to be greatest when planting early (11 March–14 April) for all cultivar types evaluated in the study. Alternatively, monetary payoffs in wet growing seasons tend to be greatest for most cultivar types (long-grain pure-lines and hybrids) when planted later (15 April–14 May). Monetary payoffs for herbicide-tolerant non-hybrids are significantly smaller relative to other cultivar types when planting occurs in the middle (15 April–14 May) and late (15 May–30 June) planting periods, indicating hybrids and long-grain pure-lines should be considered rather than herbicide-tolerant cultivars when early planting is not feasible. The results of this study should be placed in the proper context since data for this study come from the RREC near Stuttgart, Ark. The results of this study are thus more applicable to east-central Arkansas, or more specifically the Grand Prairie region of Arkansas.

Acknowledgments

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Literature Cited

Blanche, S.B. and S.D. Linscombe. 2009. Stability of rice grain and whole kernel milling yield as affected by cultivar and date of planting. Agron. J. 101:522-528.

Clayton, T.L., E. Castaneda-Gonzalez, J.T. Hardke, D.L. Frizzell, K.F. Hale, T.D. Frizzell, L.R. Amos, A. Ablao, K.A.K. Moldenhauer, and X. Sha. 2021. 2020 Degree-Day 50 (DD50) thermal unit thresholds for new rice cultivars and seeding date studies. *In*: J. Hardke, X. Sha, and N. Bateman (eds.) B.R. Wells Arkansas Rice Research Studies 2020. Arkansas Agricultural Experiment Station Research Series 676:200-209. Fayetteville.

Gautam, T.K., K.B. Watkins, and J.T. Hardke. 2021. Estimating the impact of rice planting date and cultivar type on rice economic returns in Arkansas. *In*: J. Hardke, X. Sha, and N. Bateman (eds.) B.R. Wells Arkansas Rice Research Studies 2020. Arkansas Agricultural Experiment Station Research Series 676:309-312. Fayetteville.

Gravois, K.A. and R.S. Helms. 1998. Seeding date effects on rough rice yield and head rice and selection for stability. Euphytica 102:151-159.

Sha, X.Y and S.D. Linscombe. 2007. Planting date affects grain and milling yields of water-seeded Clearfield rice. Agron. J. 99:1143-1150.

Slaton, N.A., S.D. Linscombe, R.J. Norman, and E.E. Gbur, Jr. 2003. Seeding date effect on rice grain yields in Arkansas and Louisiana. Agron. J. 95:218-223.

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

USDA-NASS. 2022a. United States Department of Agriculture, National Agricultural Statistics Service. Quick Stats (Searchable Database). Accessed 18 January 2022. Available at: https://quickstats.nass.usda.gov/

USDA-NASS. 2022b. United States Department of Agriculture, National Agricultural Statistics Service, Arkansas Field Office. Crop Progress & Condition, 2012–2021. Accessed 3 January 2022. Available at: https://www.nass.usda.gov/Statistics_by_State/Arkansas/Publications/Crop_Progress_&_Condition/index.php

USDA-FSA. 2022. United States Department of Agriculture, Farm Service Agency. Rice Program. Accessed 18 January 2022. Available at: https://www.fsa.usda.gov/programs-and-services/price-support/commodity-loans/non-recourse-loans/rice-program/index

Walker, O.L. A.G. Nelson, and C.E. Olson. 1984. Educational programs for risky decision making. Chapter 12 in P.J. Barry (ed.) Risk Management in Agriculture. The Iowa State University Press, Ames, Iowa, 1984:166-179.

Watkins, K.B., and T.K. Gautam. 2021. An overview of rice prevented planting acres in Arkansas, 2011 to 2020. *In:* J. Hardke, X. Sha, and N. Bateman (eds.) B.R. Wells Arkansas Rice Research Studies 2020. Arkansas Agricultural Experiment Station Research Series 676:317-321. Fayetteville.

Table 1. Percent Arkansas Rice Area Planted by Planting Window, 2012–2021.

Year	Early Planting Window (11 March–14 April)	Middle Planting Window (15 April–14 May)	Late Planting Window (15 May–30 June)
	(%)	(%)	(%)
2012	49	50	1
2013	9	51	40
2014	17	65	18
2015	21	65	14
2016	55	41	4
2017	67	28	5
2018	27	65	8
2019	19	34	47
2020	8	68	24
2021	26	61	13
Average	30	53	17
Wet Season[a]	12	51	37
Dry Season[b]	57	40	3
Normal Season[c]	23	64	13

[a] Wet Seasons include the years 2013, 2019, and 2020.
[b] Dry Seasons include the years 2012, 2016, and 2017.
[c] Normal Seasons include the years 2014, 2015, 2018, and 2021.
Source: Derived from USDA-NASS, Arkansas Field Office. Crop Progress & Condition, 2012–2021.

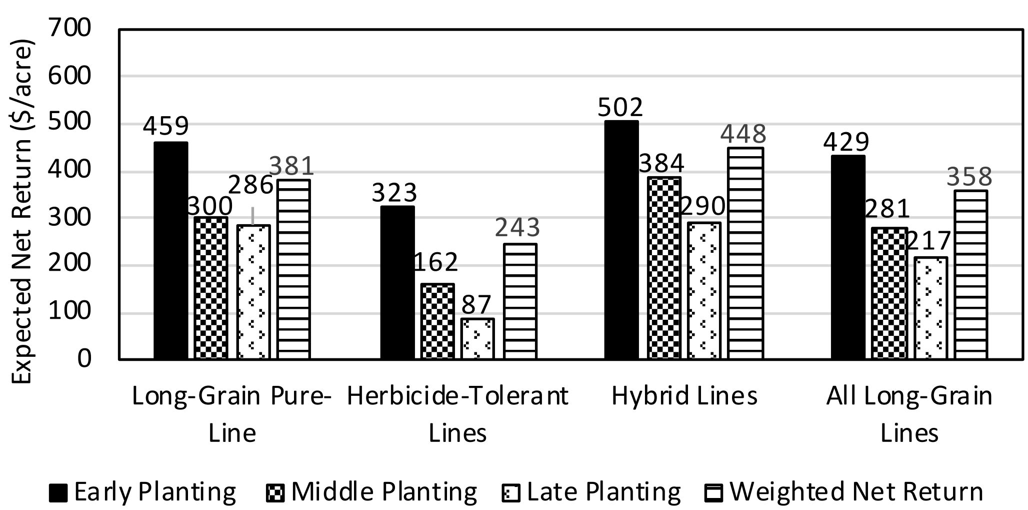

Fig. 1. Dry growing season: expected net returns (payoffs) by rice cultivar type and planting window (early planting window: 11 March–14 April; middle planting window: 15 April–14 May; late planting window: 15 May–30 June. Weighted net return: expected net return for each rice cultivar weighted by the percentage of acres planted in each planting window).

Fig. 2. Wet growing season: expected net returns (payoffs) by rice cultivar type and planting window (early planting window: 11 March–14 April; middle planting window: 15 April–14 May; late planting window: 15 May–30 June. Weighted net return: expected net return for each rice cultivar weighted by the percentage of acres planted in each planting window).

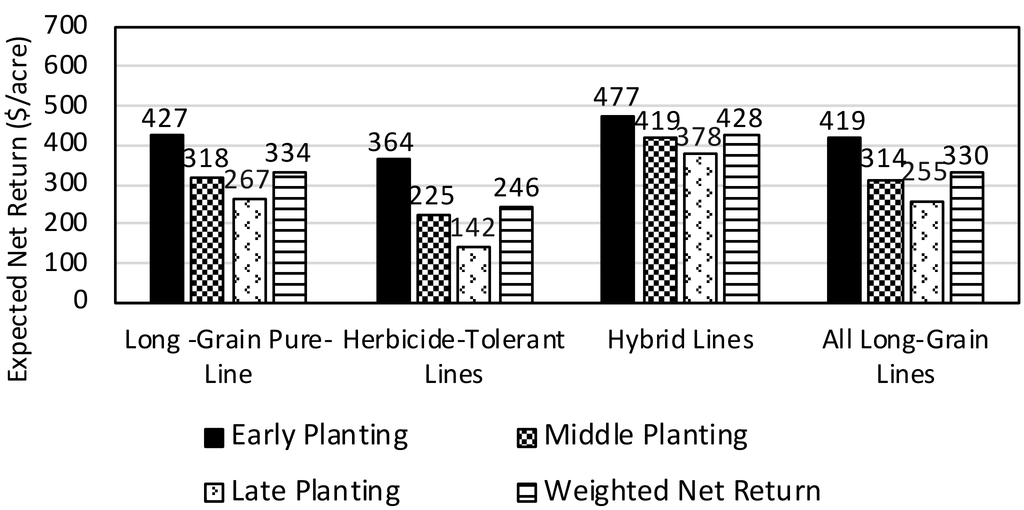

Fig. 3. Normal growing season: expected net returns (payoffs) by rice cultivar type and planting window (early planting window: 11 March–14 April; middle planting window: 15 April–14 May; late planting window: 15 May–30 June. Weighted net return: expected net return for each rice cultivar weighted by the percentage of acres planted in each planting window).

APPENDIX: RICE RESEARCH PROPOSALS

2021–2022 Rice Research Proposals

Principal Investigator (PI)	Co-PI	Proposal Name	Year of Research	Funding Amount (US$)
Non-Ecosystems				
T. Barber	J. Norsworthy and T. Butts	A team approach to improved weed management in rice	3 of 3	255,000
J. Hardke	T. Roberts, X. Sha, C. De Guzman, E. Shakiba, N. Bateman, and Y. Wamishe	Agronomic production practices for rice	3 of 3	115,000
J. Hardke	T. Roberts, X. Sha, C. De Guzman, and E. Shakiba	DD50 thermal unit thresholds and seeding date effects for new cultivars	3 of 3	70,000
J. Hardke	T. Roberts	Optimum rice plant spacing and seeding rate	3 of 3	11,000
J. Hardke	T. Roberts, X. Sha, and C. De Guzman	Nitrogen recommendations for new rice cultivars	3 of 3	64,000
N. Bateman	G. Lorenz and B. Thrash	Rice insect control, 2021	3 of 3	130,000
T. Roberts	J. Hardke	Nitrogen management tools for Arkansas rice producers	3 of 3	120,000
T. Roberts	J. Hardke	Rice fertilization-developing novel methods to assess nutrient availability to Arkansas rice	3 of 3	58,000
Y. Wamishe	J. Hardke X. Sha, E. Shakiba, D. Ahrent, and C. De Guzman	Evaluation of fungicide application timing and coverage to suppress false smut and sheath blight of rice	3 of 3	29,000
B. Watkins	A. Durand-Morat and R. Mane	Economic analysis of Arkansas rice farms	3 of 3	60,000
C De Guzman	X. Sha, E. Shakiba, R. Scott, J. Hardke, P. Counce, N. Bateman, Y. Wamishe, and T. Siebenmorgen	Breeding and evaluation for improved rice varieties (Project No. ARK02530)	3 of 3	320,000
X. Sha	E. Shakiba and C. De Guzman	Quality analysis for rice breeding and genetics	1 of 3	113,000
X. Sha	C. De Guzman, J. Hardke, T. Butts, P. Counce, N. Bateman, E. Shakiba, T. Siebenmorgen, T. Roberts, and Y. Wamishe	Development of superior medium-grain and long-grain rice varieties for Arkansas and the mid-south	3 of 3	330,000

Continued

2021–2022 Rice Research Proposals, continued.

Principal Investigator (PI)	Co-PI	Proposal Name	Year of Research	Funding Amount (US$)
Ecosystems				
E. Shakiba		Breeding and developing hybrid rice cultivars for the southern USA	1 of 3	200,000
K.Moldenhauer	X. Sha, E. Shakiba, and C. De Guzman	Marker-assisted selection for advanced rice breeding and genetics	3 of 3	157,000
J. Hardke	T. Roberts, X. Sha, C. De Guzman, E. Shakiba, and Y. Wamishe	Arkansas rice performance trials	3 of 3	102,000
C. DeGuzman	Y. Wamishe	Rice breeding and pathology tech support	3 of 3	140,000
Y. Wamishe	J. Hardke, K. Moldenhauer, X. Sha, E. Shakiba, and D. Ahrent	Evaluation of contemporary rice to straighthead, a physiological disorder of unknown cause	3 of 3	13,000
C. Rojas		Investigating genetic basis of resistance to bacterial panicle blight of rice under heat stress conditions	3 of 3	27,000
C. Rojas	A. Rojas	Control of rice diseases in Arkansas by using antagonistic bacteria and products derived from them	3 of 3	28,000
A. Pereira	P. Counce	Improving grain yield and quality under high nighttime temperature using functional gene markers	3 of 3	35,000
J. Hardke		Rice research verification program	3 of 3	106,500
T. Siebenmorgen	G. Atungulu and Y-J. Wang	Identification of cultivar attributes that impact rice milling and functional characteristics	3 of 3	64,000
A. Poncet	J. Norsworthy, T. Roberts, and J. Hardke	Automatic detection of weed patches in rice fields using remote sensing technology	New	30,000
N. Slaton		Editing and publishing B.R. Wells Rice Research studies (2020)	Ongoing	4,000
V. Ford	B. Watkins	Rice enterprise budgets and production economic analysis	Ongoing	8,500
A. Durand-Morat	B. Watkins and R. Mane	Analysis of farm policy programs and competitiveness of Arkansas and U.S. rice	2 of 3	20,000
J. Hardke	T. Roberts, X. Sha, C. De Guzman, E. Shakiba, G. Lorenz, N. Bateman, and Y. Wamishe	Agronomics of Alternative Irrigation Strategies for Rice	5 of 5	75,000
C. Henry	R. Mane and K. Brye	Developing and improving irrigation tools for rice	3 of 3	90,000
			Total:	**2,775,000**

DIVISION OF AGRICULTURE

RESEARCH & EXTENSION

University of Arkansas System