8-2020

B.R. Wells Arkansas Rice Research Studies 2019

K.A. K. Moldenhauer

B. Scott

J. Hardke

Citation

Moldenhauer, K. K., Scott, B., & Hardke, J. (2020). B.R. Wells Arkansas Rice Research Studies 2019. *Arkansas Agricultural Experiment Station Research Series.* Retrieved from https://scholarworks.uark.edu/aaesser/163

B.R. Wells

ARKANSAS RICE RESEARCH STUDIES 2019

K.A.K. Moldenhauer, B. Scott, and J. Hardke, editors

DIVISION OF AGRICULTURE
RESEARCH & EXTENSION
University of Arkansas System

ARKANSAS AGRICULTURAL EXPERIMENT STATION
August 2020 Research Series 667

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

Cover Photo: Dr. Karen Moldenhauer, professor and plant breeder in the department of Crop, Soil, and Environmental Sciences, shows cross pollinated plants in the Rice Research and Extension Center breeding nursery, Stuttgart.

Photo credit: Fred Miller, University of Arkansas System Division of Agriculture Communications.

Layout and editing by Gail Halleck

Arkansas Agricultural Experiment Station (AAES), University of Arkansas System Division of Agriculture, Fayetteville. Mark J. Cochran, Vice President for Agriculture. Jean-François Meullenet, AAES Director and Senior Associate Vice-President for Agriculture–Research. WWW/CC2020.

ISSN:1941-2177 CODEN:AKAMA6

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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

Karen Moldenhauer

This was supposed to be a story about Karen Moldenhauer, who was retiring after a ridiculous number of years developing improved rice varieties for Arkansas farmers. But a funny thing happened on the way to retirement. Moldenhauer was appointed interim director of the Rice Research and Extension Center. And that changed everything.

Well, not everything, really, because it doesn't erase 38 years of dedication to the art and science of plant breeding. Longer than that, in fact, because we can't ignore the years of graduate school. Moldenhauer earned a master's degree in plant breeding and cytogenetics from North Carolina State University in 1977 and a Ph.D. in plant breeding from Iowa State University in 1982. She is expert in the exacting techniques and meticulous recordkeeping required to move ragged little plants from exotic parts of the world step-by-step, year after year, generation following generation until a promising breeding line she refers to as "one of my babies" is ready to step through a curtain of administrative red tape onto the stage of public rice varieties that help feed the world.

I hope I'm not overstating it, but I don't think I am.

And the funny thing that happened on the way to retirement is not so funny, because it's not the first time. The University of Arkansas System Division of Agriculture called on Moldenhauer to lead the RREC as interim director in 2001-2002.

But let's not outrun the story here.

After earning her doctorate, Moldenhauer joined the Division of Agriculture in 1982 as an assistant professor of agronomy and a rice breeder for the Arkansas Agricultural Experiment Station, posted at the Rice Research and Extension Center near Stuttgart. She was promoted to associate professor in 1987, and professor in 1992. Following her first stretch as interim RREC director, Moldenhauer was named the first holder of the Rice Industry Chair for Variety Development in 2002, an endowed position that she still holds.

Moldenhauer's primary research focuses on improving grain yield, cooking quality characteristics and disease resistance. Her releases Drew, Kaybonnet, and Katy were the first commercially available cultivars with resistance to all of the common blast races in the southern U.S. growing region. They have provided a source of rice blast resistance to the rice breeding groups in Louisiana, Mississippi and Texas. During Moldenhauer's tenure as project leader for the rice breeding and cultivar development program, 38 rice cultivars have been released to producers and grown on 21 million acres over the past 38 years. That's not a typo — 38 cultivars in 38 years. Take a moment to enjoy the symmetry, and then let's move on.

Division of Agriculture cultivars have had a substantial impact on rice production in Arkansas, helping to increase the state average rice yields from 95 bushels per acre in 1982 to as high as 168 bushels per acre in 2013 and 2014. These Arkansas varieties averaged 50 percent to 60 percent of the state's rice acreage in any given year from 1982 until 2009, when commercial hybrid rice varieties became popular. Despite the tremendous popularity of high-yielding hybrids, Division of Agriculture varieties continue to average 20 percent to 30 percent of the Arkansas rice acreage each year. Diamond, a 2016 variety release with excellent yield potential, was adopted by many Arkansas producers and grown on approximately 20 percent of the acreage in 2018 and 14 percent of the acreage in 2019. That's the largest number of acres for any pure line variety in either year.

Moldenhauer has also rolled up her sleeves to advance the RREC's research infrastructure. She established a rice biotechnology program in 1989 where she developed important breeding tools like anther culture and marker assisted selection to complement the existing rice breeding program. The program developed into the center's Molecular Laboratory.

She also has been involved in many interdisciplinary cooperative research efforts including joint research planning, management and field evaluation for rice studies involving soil fertility for the DD50 program, and nitrogen interaction studies. She worked with plant pathologists to develop nurseries for the investigation of recurrent selection for sheath blight tolerance, rice blast inheritance studies, sheath blight, blast and kernel smut. And she worked with food scientists to research and improve rice kernel characteristics and food quality traits.

They say the job's not over until the paperwork is finished, and Moldenhauer's paperwork is impressive by any measure. She has 14 utility patents and 12 plant variety protection certificates. She published 11 book chapters, 90 refereed publications, 272 reviewed publications, and 139 Abstracts.

Moldenhauer is widely recognized for her career accomplishments. She is a Fellow of the Crop Science Society of America, the American Society of Agronomy and the American Association for the Advancement of Science. She has received numerous awards including the Rice Technical Working Group Distinguished Service Award in 2020, and the Distinguished Rice Research and Education Team Award in 2002 and 2004. She received the University of Arkansas System Division of Agriculture John White Outstanding Research Team Award in 2004 and the Friend of the Farmer Award, from Riceland Foods in 2001.

Always active in her discipline, Moldenhauer has served on numerous committees for the University of Arkansas and professional organizations over the years. She was on the Board of Trustees for the International Rice Research Institute of Los Baños, Philippines, from 2016-2018 and served as vice chair of the organization's Audit Committee from 2017-2018. She also served on the National Genetic Resources Advisory Council from 2011 to 2017, the Plant Breeding Coordinating Committee SCC-80 from 2005 to the present and its executive committee from 2008 to 2012. She served on the U.S. Rice Federation Rice Marketability and Competitiveness Task Force as technical advisor from 2014 to the present. She served on the U.S. Rice Federation Rice Technology Task Force from 2000 to 2007 and was elected chair of the Crop Science Society of America, Division C-1 in 2001, which included serving as chair elect, division chair and past chair from 2002 to 2004. She has also been a member of the National Crop Germplasm Committee/Crop Germplasm Committee,1986-1988, 1998-2019, and the chair form 2001-2006.

In her career of nearly four decades, Moldenhauer has demonstrated a creative and disciplined approach to research and development, constantly searched for new technologies and methodologies to improve the investigation, and has been willing to take on new challenges and responsibilities. She imparts a legacy that will inspire the next generations of researchers at the Rice Research and Extension Center.

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, 2019

J.T. Hardke[1]

Abstract

Arkansas is the leading rice producer in the United States. The state represents 45.6% of total U.S. rice production and 47.1% of the total acres planted to rice in 2019. 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 leads to variation in the adoption and utilization of different crop management practices. To monitor and better understand changes in rice production practices, including adoption of new practices, a survey was initiated in 2002 to record annual production 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's Degree-Day 50 (DD50) Rice Management Program enrollment.

Results and Discussion

Rice acreage by county is presented in Table 1 with distribution of the most widely produced cultivars. The cultivar RT XP753 was the most widely planted in 2019 at 25.6% of the acreage, followed by RT Gemini 214 CL (15.0%), Diamond (10.9%), RT CLXL745 (9.7%), Jupiter (9.5%), Titan (6.5%), RT XP760 (4.6%), RT 7311 CL (4.0%), CL153 (3.8%), and CL151 (2.1%). Additional cultivars of importance in 2019, though not shown in the table, were RT XL723, PVL01, LaKast, RT CLXP756, Roy J, CL111, RT CLXL729, and CL172.

Arkansas planted 1,156,000 acres of rice in 2019 which accounted for 45.5% of the total U.S. rice acres (Table 2). The state-average yield of 7480 lb/ac (166.2 bu./ac) represented a 40 lb/ac decrease compared to 2018. This represented the fifth highest state average yield for Arkansas on record (tied with 2012). Mild overall temperatures and regular rainfall throughout the season seemed primarily responsible for favorable rice growth and development leading to favorable yields. A late heatwave in August and September allowed some later-planted rice to achieve more successful yields than would traditionally be expected. Final harvested acreage in 2019 totaled 1,126,000. The total rice produced in Arkansas during 2019 was 84.3 million hundredweight (cwt). This represents 45.6% of the 184.7 million cwt produced in the U.S. during 2019. Over the past three years, Arkansas has been responsible for 46.6% of all rice produced in the U.S. The seven largest rice-producing counties by acreage in Arkansas during 2019 included Poinsett, Lawrence, Arkansas, Cross, Jackson, Lonoke, and Clay, representing 45.6% of the state's total rice acreage (Table 1).

Planting in 2019 fell immediately behind the 5-year average beginning in April due to cool conditions with regular rainfall events (Fig. 1). Planting progress had reached only 19% by 14 April compared to 34% averaged across the previous five years. Planting progress continued slowly throughout April, May, and June. By 12 May, only 53% of acres had been planted compared to an average of 90% by this date across the five previous seasons. By 9 June, 95% of acres had been planted compared to the five-year average of 99%. As harvest began, temperatures increased while humidity and rainfall events were minimal allowing for

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

a surprisingly rapid harvest as the crop quickly matured. By 15 September, harvest progress had reached 44% which was similar to the 48% for the 5-year average (Fig. 2). About 72% of the crop had been harvested by 29 September compared with 78% harvest progress on the same date in previous years. However, it should be noted that many acres harvested in late September and beyond were harvested during periods of increased rainfall and heavy dew. Harvest progress was complete (100%) by 10 November, approximately two weeks earlier than for 2018.

Approximately 51% of the rice produced in Arkansas was planted using conventional tillage methods in 2019 (Table 3). This usually involves fall tillage when the weather cooperates, followed by spring tillage to prepare the seedbed. The remainder of rice acres were planted using stale seedbed (38.7%) or no-till (10.0%) systems. True no-till rice production is not common but is practiced in a few select regions of the state; however, delayed planting due to wet conditions may have led to an increase in no-till acres in 2019.

More rice is produced on silt loams soils (50.5%) than any other soil texture (Table 3). Rice production on clay or clay loam soils (24.4% and 20.7%, respectively) has become static over recent years after steadily increasing through 2010. These differences in soil type present unique challenges in rice production such as tillage practices, seeding rates, fertilizer management, and irrigation.

Rice most commonly follows soybean in rotation, accounting for 67.6% of the rice acreage (Table 3). Approximately 24% of the acreage in 2019 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 5.2% using a water-seeded system. Annually, approximately 84% 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 and reusing all available water. Simultaneously, producers have tried to implement other conservation techniques to preserve the resource vital to continued production. Groundwater is used to irrigate 77.4% of the rice acreage in Arkansas with the remaining 22.6% 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 irrigation which uses poly-tubing as a means of irrigating rice to conserve water and labor. As of 2019, rice farmers utilize this practice on 30.4% of the rice acreage (Table 3). Most remaining acreage is still irrigated with conventional levee and gate systems. Intermittent flooding is another means of irrigation increasing in interest recently as a means to reduce pumping costs and water use, but the practice accounts for only 2.8% of acreage at this time. Additional interest has risen in growing rice in a furrow-irrigated system (row rice) as is common with soybean or corn as a means to simplify crop rotation and management and currently accounts for 10.5% of acreage compared to 7.7% and 3.5% of acreage in 2018 and 2017, 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 2019, 26.1% of the acreage was burned, 34.9% was tilled, 37.6% was rolled, and 28.8% was winter flooded (Table 3). Combinations of these systems are used in many cases. For example, a significant amount of the acreage that is flooded during the winter for waterfowl will also be rolled. Some practices are inhibited by fall weather, and the wet fall weather in 2018 and 2019 resulted in a decrease in burning and tillage, but a subsequent rise in rolling and winter flooding.

Contour levee fields accounted for 48.9% of rice acres in 2019 (Table 3). Precision-leveled, or straight levee, fields represented 38.3% and zero-graded fields 12.8%. Each year growers attempt to make land improvements where possible to improve overall rice crop management, particularly related to water management. Modifying the slope, and subsequently the levee structure and arrangement in fields, can have a profound impact on the efficiency of rice production. Straight levee and zero-grade fields have been shown to reduce water use significantly in rice production in Arkansas.

The use of yield monitors at harvest (77.1%) and grid soil sampling (37.9%) have increased slightly in recent years (Table 3). However, only 23.7% of rice acres are fertilized using variable rate equipment. Urea stabilizers [products containing N-(n-butyl) thiophosphoric triamide (NBPT)] are currently used on 90.0% 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 6.0% of acres, but additional tools are being developed to improve confidence and adoption of this practice. In addition, programs such as Pipe Planner, PHAUCET, and MIRI Rice Irrigation were used on 33.3% of rice acres in 2019. The GreenSeeker handheld was used to monitor in-season nitrogen conditions on 3.8% of acres. The use of cover crops in rice rotations remains limited, but was a practice used on 3.0% of acres. Harvest aid applications, primarily sodium chlorate, are currently used on 32.2% of acres to improve harvest efficiency.

Pest management is vital to preserving both yield and quality in rice. Foliar fungicide applications were made on 52.0% of rice acres in 2019 (Table 3). Conditions were not as favorable for the development of disease during the 2019 season. Approximately 49% 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 80.1% 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.

Clearfield rice continues to play a significant role in rice production in Arkansas. This technology (all cultivars combined) accounted for 37% of the total rice acreage in 2019 (Fig. 3). Proper stewardship of this technology will be the key to its continued success on the majority of rice acres. In areas where stewardship has been poor, imadazolinone-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. A new herbicide-resistant technology, Provisia, became available on limited acres beginning in 2018, and in 2019 was planted on 1.4% of acres. Acres of this and other herbicide technologies will likely increase in the coming years.

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 166 bu./ac in 2017–2019, an increase of 31 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

The author would like to extend thanks to the rice farmers of Arkansas who provide support through the rice check-off program; all of the county agents who participated in this survey; the University of Arkansas System Division of Agriculture for support, and the members of the Rice Agronomy crew: Donna Frizzell, Eduardo Castaneda-Gonzalez, Wesley Plummer, Trent Frizzell, Ken Hale, Chuck Pipkins, Ralph Mazzanti, and Ron Baker. Special thanks to county agriculture agents who assisted with the survey: Craig Allen, Mike Andrews, Bryce Baldridge, Kurt Beaty, Grant Beckwith, Matthew Davis, John David Farabough, Dave Freeze, Robert Goodson, Brett Gordon, Brent Griffin, Cody Griffin, Robert Harper, Shawn Lancaster, Kevin Lawson, Kevin Norton, Russ Parker, Keith Perkins, Bob Powell Nathan Reinhardt, Stewart Runsick, Jennifer Sansom, Andrew Sayger, Amy Simpson, Phil Sims, Steven Stone, Branon Thiesse, Kevin Van Pelt, Rick Wimberley, and Jan Yingling.

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Table 1. 2019 Arkansas harvested rice acreage summary.

	Harvested Acreage[a]		Medium-grain			Long-grain								
County	2018	2019	Jupiter	Titan	Others[b]	CL151	CL153	Diamond	RT7311 CL	RT CLXL745	RT Gemini 214 CL	RT XP753	RT XP760	Others[b]
Arkansas	79,435	74,687	2,604	1,027	269	2,061	2,439	6,924	2,513	9,201	14,295	21,796	3,709	7,849
Ashley	6,616	5,409	0	0	0	0	0	0	0	4,720	690	0	0	0
Chicot	23,642	17,880	843	0	0	341	2,003	0	0	0	768	3,204	0	10,721
Clark	3,368	1,860	0	0	0	0	0	752	0	0	0	1,108	0	0
Clay	81,418	64,931	5,022	672	0	4,081	5,377	4,034	2,812	1,032	5,977	12,812	2,543	20,569
Craighead	74,033	53,183	12,417	2,029	0	3,821	7,959	4,086	2,275	3,705	6,577	10,037	57	219
Crittenden	46,808	43,743	1,928	6,354	341	0	0	4,044	0	2,109	2,047	22,924	3,470	526
Cross	85,735	71,600	8,574	6,834	649	1,943	6,852	8,778	2,155	6,879	7,821	15,003	3,233	2,879
Desha	17,067	20,399	2,185	2,185	0	0	333	2,705	0	926	3	8,088	505	3,469
Drew	11,890	9,137	0	0	0	0	0	0	900	4,291	0	716	2,985	245
Greene	77,653	58,606	0	3,101	0	0	0	0	3,685	6,938	27,255	17,628	0	0
Independence	12,660	5,311	938	938	0	0	1,718	344	0	0	687	687	0	0
Jackson	109,340	66,127	17,334	11,196	0	319	796	6,828	4,188	3,039	6,578	8,516	0	7,332
Jefferson	65,725	51,730	272	272	0	0	5,346	6,482	0	0	0	39,225	0	134
Lafayette	4,864	3,456	0	0	0	0	0	1,382	0	0	346	1,728	0	0
Lawrence	108,018	76,188	3,984	17,251	0	0	0	11,105	0	9,228	9,015	18,254	1,236	6,115
Lee	18,539	16,670	1,897	759	0	0	0	5,307	690	0	2,823	2,007	1,305	1,882
Lincoln	23,510	17,466	322	0	0	0	0	0	4,412	0	12,732	0	0	0
Lonoke	84,246	65,728	1,859	0	0	0	0	664	3,864	6,276	18,129	24,883	4,933	5,120
Mississippi	62,284	56,313	453	568	1,278	0	2,707	14,239	5,615	15,671	201	12,534	100	2,948
Monroe	53,666	39,999	3,498	4,397	0	2,413	1,756	6,751	0	3,194	10,191	6,583	259	956
Phillips	27,703	26,920	0	2,456	0	0	0	4,530	0	906	0	0	17,215	1,812
Poinsett	117,557	94,753	27,590	1,307	3,460	2,542	1,491	17,161	1,848	9,839	11,154	8,469	4,398	5,495
Pope	3,102	1,898	0	0	0	380	0	285	0	0	285	569	0	380
Prairie	62,398	53,623	4,091	905	384	229	990	2,308	4,119	8,139	14,602	14,599	2,140	1,116
Pulaski	5,416	2,894	0	0	85	0	0	0	0	2,809	0	0	0	0
Randolph	40,743	27,582	3,935	5,677	198	0	0	3,079	0	2,446	2,164	10,082	0	0
St. Francis	34,527	34,508	895	3,784	0	602	0	3,803	3,214	2,257	3,789	11,900	1,375	2,890
White	10,763	7,871	1,070	459	0	0	0	737	470	374	1,383	2,776	603	0
Woodruff	59,356	49,495	5,182	1,321	0	4,550	2,697	6,145	2,101	4,702	8,246	10,429	1,717	2,405
Others[c]	11,320	2,855	0	0	0	151	0	448	0	109	547	1,489	0	109
Unaccounted[d]	3,599	3,179												3,599
2019 Total		1,126,000	106,892	73,490	6,665	23,434	42,464	122,922	44,863	108,791	168,302	288,046	51,783	88,350
2019 Percent		100.00	9.49	6.53	0.59	2.08	3.77	10.92	3.98	9.66	14.95	25.58	4.60	7.85
2018 Total	1,427,000		85,826	69,947	23,840	31,834	119,988	285,444	62,326	161,438	152,995	315,971	18,287	99,104
2018 Percent	100		6.01	4.90	1.67	2.23	8.41	20.00	4.37	11.31	10.72	22.14	1.28	6.94

[a] Harvested acreage. Source: USDA-NASS, 2020.

[b] Other varieties: RT XL723, PVL01, LaKast, RT CLXP756, Roy J, CL111, RT CLXL729, CL172, CL272, RT XP754, CL163, RT7801, Caffey, CLL15, Jazzman-2, Cheniere, Wells, AB647, and Jazzman.

[c] Other counties: Conway, Faulkner, Franklin, Hot Springs, Little River, Logan, Miller, 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 2017 to 2019[a].

	Area Planted			Area Harvested			Yield			Production		
State	2017	2018	2019	2017	2018	2019	2017	2018	2019	2017	2018	2019
	-------(1,000 ac)-------			---------(1,000 ac)--------			------------(lb/ac)---------			------------(1,000 cwt[b])----------		
AR	1,161	1,441	1,156	1,104	1,422	1,126	7,490	7,520	7,480	82,644	106,947	84,257
CA	445	506	498	443	504	496	8,410	8,620	8,450	37,277	43,425	41,933
LA	400	440	425	395	436	414	6,710	7,130	6,380	26,503	31,094	26,408
MS	115	140	117	114	139	113	7,400	7,350	7,350	8,436	10,217	8,302
MO	169	224	187	160	220	173	7,440	7,770	7,370	11,900	17,090	12,747
TX	173	195	157	158	189	150	7,260	7,970	7,350	11,468	15,060	11,028
US	2,463	2,946	2,540	2,374	2,910	2,472	7,507	7,692	7,471	178,228	223,833	184,675

[a] Source: USDA-NASS, 2020.

[b] cwt = hundredweight.

Table 3. Acreage distribution of selected cultural practices for Arkansas rice production from 2017 to 2019.[a]

	2017		2018		2019	
Cultural Practice	**Acreage**	**% of Total**	**Acreage**	**% of Total**	**Acreage**	**% of Total**
Arkansas Rice Acreage	1,104,000	100.00	1,427,000	100.00	1,126,000	100.00
Soil Texture						
Clay	264,556	24.0	346,780	24.3	274,537	24.4
Clay Loam	253,048	22.9	304,652	21.3	233,341	20.7
Silt Loam	524,393	47.5	699,065	49.0	568,253	50.5
Sandy Loam	46,521	4.2	59,547	4.2	40,309	3.6
Sand	15,482	1.4	16,957	1.2	9,278	0.8
Tillage Practices						
Conventional	567,141	51.4	720,177	50.5	577,517	51.3
Stale Seedbed	482,989	43.7	616,087	43.2	435,702	38.7
No-Till	53,870	4.9	90,736	6.4	112,500	10.0
Crop Rotations						
Soybean	775,246	70.2	977,377	68.5	760,615	67.6
Rice	255,716	23.2	360,398	25.3	273,153	24.3
Cotton	810	0.1	853	0.1	1,727	0.2
Corn	41,419	3.8	49,066	3.4	51,815	4.6
Grain Sorghum	3,151	0.3	1,941	0.1	691	0.1
Wheat	810	0.1	1,194	0.1	4,693	0.4
Fallow	26,849	2.4	32,907	2.3	33,025	2.9
Other	0	0.0	3,265	0.2	0	0.0
Seeding Methods						
Drill Seeded	922,503	83.6	1,222,743	85.7	941,872	83.6
Broadcast Seeded	181,497	16.4	204,257	14.3	183,846	16.3
Water Seeded	67,271	6.1	65,185	4.6	58,156	5.2
Irrigation Water Sources						
Groundwater	808,910	73.3	1,084,271	76.0	871,110	77.4
Stream, Rivers, etc.	147,487	13.4	173,161	11.9	146,662	13.0
Reservoirs	147,603	13.4	169,568	12.1	107,946	9.6
Irrigation Methods						
Flood, Levees	659,547	59.7	804,542	56.4	633,240	56.2
Flood, Multiple Inlet	368,401	33.4	472,225	33.1	342,609	30.4
Intermittent (AWD)	36,907	3.3	39,448	2.8	31,196	2.8
Furrow	39,018	3.5	109,472	7.7	117,991	10.5
Sprinkler	127	0.0	31	0.0	682	0.1
Other	0	0.0	0	0.0	0	0.0
Stubble Management						
Burned	491,927	44.6	394,040	27.6	293,341	26.1
Tilled	522,690	47.3	516,563	36.2	392,884	34.9
Rolled	264,858	24.0	566,202	39.7	423,440	37.6
Winter Flooded	226,776	20.5	388,461	27.2	324,686	28.8
Land Management						
Contour levees	528,556	47.9	684,144	47.9	550,470	48.9
Precision-level	418,990	38.0	560,541	39.3	430,754	38.3
Zero-grade	156,454	14.2	182,315	12.8	144,495	12.8
Precision Agriculture						
Yield Monitors	779,179	70.6	1,060,779	74.3	867,793	77.1
Grid Sampling	395,431	35.8	541,455	37.9	426,851	37.9
Variable-rate Fertilizer	280,321	25.4	419,201	29.4	267,024	23.7
Use Pipe Planner, Phaucet	--	--	410,652	28.8	374,956	33.3
Use urea stabilizer (NBPT)	857,937	77.7	1,154,964	81.1	1,013,281	90.0
N-STaR	52,073	4.7	76,609	5.4	68,079	6.0
Use GreenSeeker handheld	--	--	--	--	42,352	3.8
Use Cover Crops	--	--	--	--	34,240	3.0
Use Sodium Chlorate	--	--	--	--	362,652	32.2
Pest Management						
Insecticide Seed Treatment	811,813	73.5	1,054,757	73.9	902,444	80.1
Fungicide (foliar app.)	684,889	62.0	808,878	56.7	585,688	52.0
Insecticide (foliar app.)	492,395	44.6	555,505	38.9	546,795	48.6

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

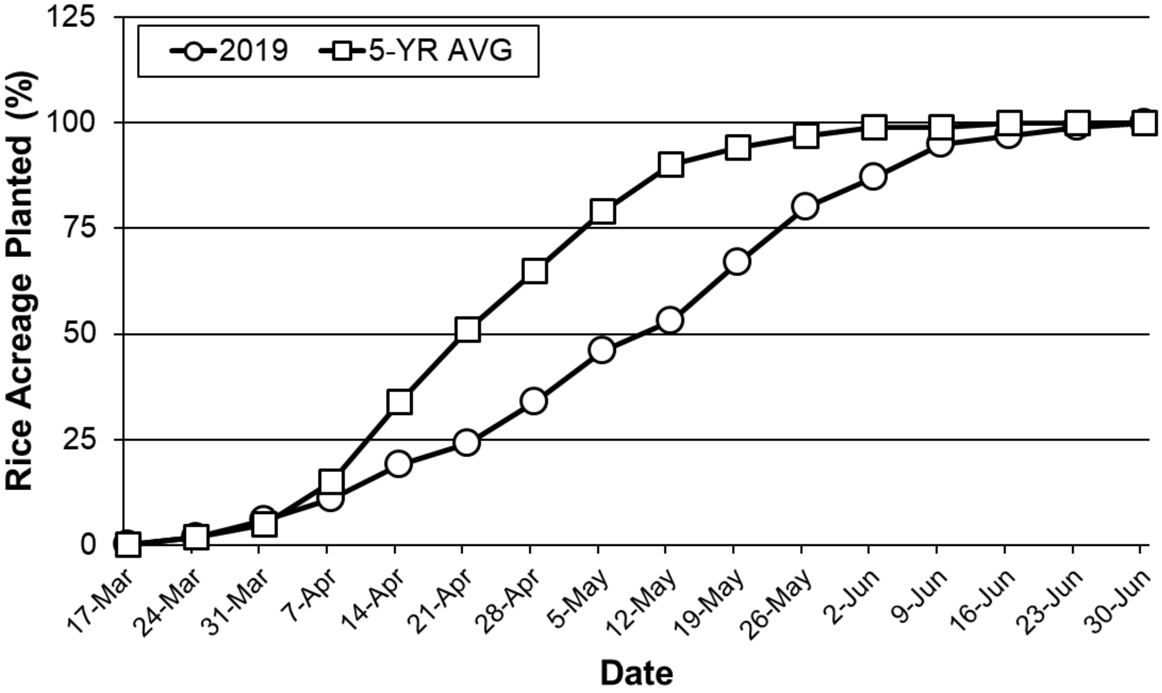

Fig. 1. Arkansas rice planting progress during 2019 compared to the five-year state average (NASS, 2020).

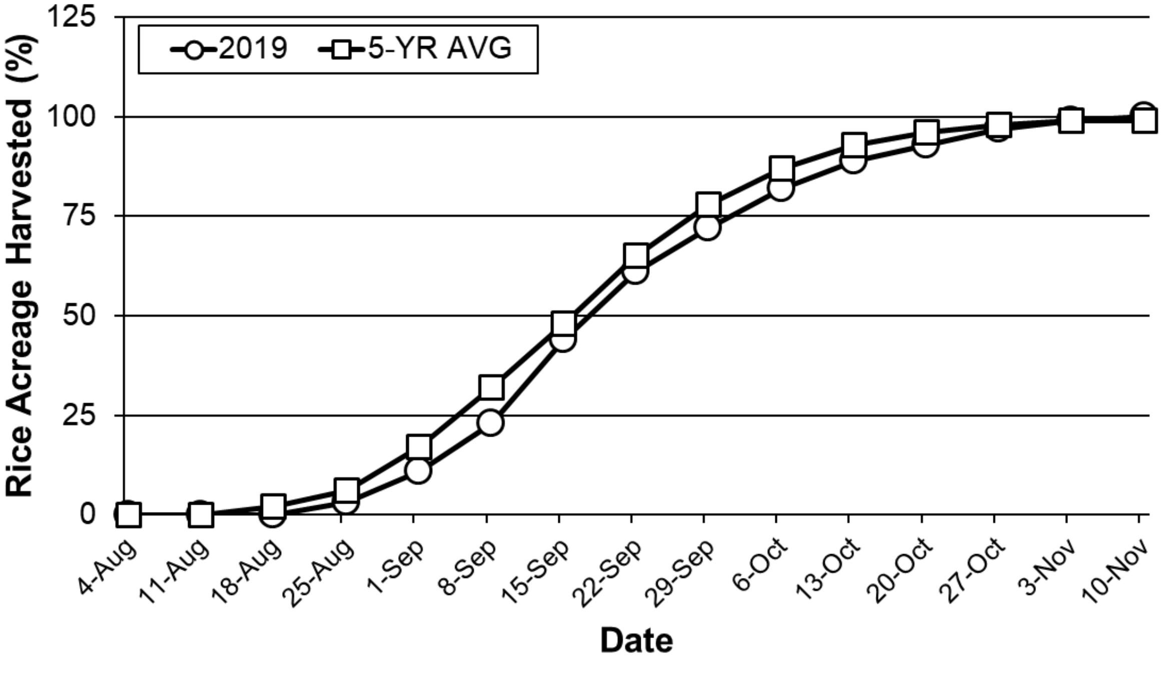

Fig. 2. Arkansas rice harvest progress during 2019 compared to the five-year state average (NASS, 2020).

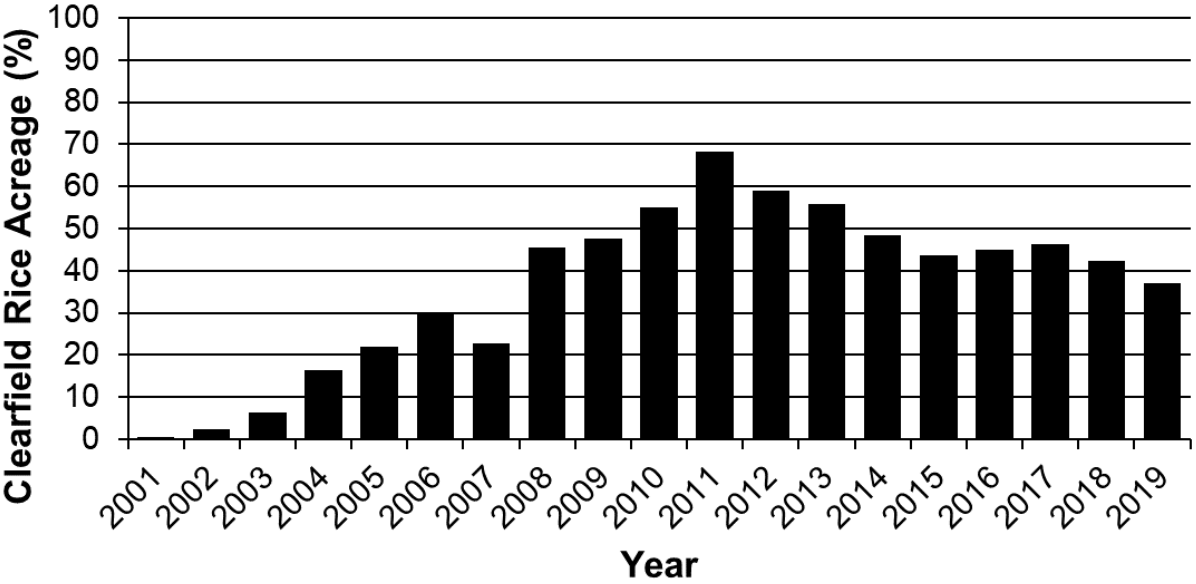

Fig. 3. Percentage of Clearfield rice cultivars planted in Arkansas between 2001 and 2019.

2019 Rice Research Verification Program

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

Abstract

The 2019 Rice Research Verification Program (RRVP) was conducted on 15 commercial rice fields across Arkansas. Counties participating in the program included Arkansas, Chicot, Craighead, Crittenden, Desha, Jackson, Jefferson, Lawrence, Lee, Lincoln, Lonoke, Monroe, Randolph, White and Woodruff for a total of 830 acres. Grain yield in the 2019 RRVP averaged 183 bu./ac, ranging from 164 to 214 bu./ac. The 2019 RRVP average yield was 17 bu./ac greater than the estimated Arkansas state average of 166 bu./ac. The highest yielding field was in Craighead County with a grain yield of 214 bu./ac. The lowest yielding field was in Desha County and produced 164 bu./ac. Milling quality in the RRVP averaged 57/70 (% head rice/% total milled rice).

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 492 commercial rice fields in 33 rice-producing counties in Arkansas. Since the program's inception 36 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 to monitor type and level of weed, disease and insect infestation for possible pesticide applications.

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

Counties participating in the program during 2019 included Arkansas, Chicot, Craighead, Crittenden, Desha, Jackson, Jefferson, Lawrence, Lee, Lincoln, Lonoke, Monroe, Randolph, White and Woodruff. The 15 rice fields totaled 830 acres enrolled in the program. Five different cultivars were seeded: Diamond (6 fields); RiceTec [RT] XP753 (5 fields); RT Gemini 214 CL (2 fields); RT CL XP4534 (1 field); and RT CLXL745 (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, midseason nitrogen levels, grain yield, milling yield, and grain quality.

Results and Discussion

Yield

The average RRVP yield was 183 bu./ac with a range of 164 to 214 bu./ac (Table 1). All grain yields of RRVP fields are reported in dry bushels corrected to 12% moisture. The RRVP average was 17 bu./ac more than the estimated state average yield of 166 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 Craighead County field, seeded with RT XP753, was the highest yielding RRVP field at 214 bu./ac. Fourteen of the fifteen fields enrolled in the program exceeded 170 bu./ac.

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[1] Rice Verification Program Coordinator, Rice Verification Program Coordinator, and Rice Extension Agronomist, respectively, Department of Crop, Soil, and Environmental Sciences, Stuttgart.

[2] Professor, Economics, Rice Research and Extension Center, Stuttgart.

Desha County encountered a late planting date resulting in the lowest yielding field with RT CLXL745 producing 164 bu./ac.

Milling data was recorded on all of the RRVP fields. The average milling yield for the 15 fields was 55/70 (% head rice/ % total milled rice). The highest milling yield was 64/73 with RT CLXL745 in Desha County (Table 1). The lowest milling yield was 45/69 with RT XP753 in Craighead County. A milling yield of 55/70 is considered the standard used by the rice milling industry.

Planting and Emergence

Planting began with Chicot and Jefferson Counties on 3 April and ended with Lincoln County on 4 June (Table 1). Nine of the verification fields were planted in April, five in May, and one in June. An average of 80 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 12 days was required for emergence. Stand density averaged 18 plants/ft² for pure-line varieties and 6 plants/ft² 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 all 15 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, various issues unrelated to N-STaR triggered the decision to apply additional N in 2 fields at some point in the season. The issues prompting these 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 take into account a combination of factors including soil texture, previous crop, and cultivar requirements (Tables 1 and 2). The GreenSeeker hand-held crop sensor was used at least weekly in all fields after panicle initiation through late boot stage in order 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 Arkansas, Chicot, Craighead, Desha, Lee, Lonoke, White and Woodruff County fields. Potassium was applied to Arkansas, Craighead, Lee, Jackson, Lonoke, Randolph, White and Woodruff Counties. Zinc was applied as a pre-plant fertilizer to fields in Arkansas, Lee, Lonoke, Monroe, Randolph, White and Woodruff Counties, while zinc seed treatment was used with all hybrid rice cultivars at a rate of 0.5 lb Zn/100 lb seed. The average per acre cost of fertilizer across all fields was $114.37.

Weed Control

Clomazone (Command) herbicide was utilized as either a stand-alone, premix or tank mix application in all 15 program fields for early-season grass control (Table 3). Quinclorac (Facet) was utilized in 6 of 15 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 13 of 15 fields. All 15 fields utilized a combination of both grass and broadleaf residuals. Four fields (Chicot, Desha, Lincoln, and Randolph Counties) were seeded in Clearfield cultivars (Table 1). All of these utilized Clearfield technology herbicides (Table 3).

Disease Control

A foliar fungicide was applied in 2 of the 15 program fields (Jackson and Woodruff Counties). These were preventive treatments applied for kernel smut, false smut and rice blast 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. Fifteen fields had a seed treatment containing a fungicide.

Insect Control

Eight fields (Arkansas, Chicot, Jackson, Jefferson, Lawrence, Monroe, Randolph and White Counties) were treated with a foliar insecticide application for rice stink bug (Table 4). Fourteen fields received an insecticide seed treatment.

Irrigation

Well water was used exclusively for irrigation in 12 of the 15 fields in the 2019 RRVP while 4 fields (Desha, Lincoln, Randolph and White Counties) were irrigated exclusively with surface water. Three fields (Chicot, Desha and Lincoln Counties) were zero-grade. Two fields (Chicot and Craighead County) were furrow irrigated (row rice). Multiple Inlet Rice Irrigation (MIRI) was utilized in 10 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 12 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 in.) was used. The difference in irrigation water used was due in part to rainfall amounts which ranged from a low of 8.2 in. to a high of 68.7 in.

Economic Analysis

This section provides information on production costs and returns for the 2019 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 16 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 2019 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 $388.32/ac for Jefferson County to $767.80/ac for Woodruff County, while operating costs per bushel ranged from $2.16/bu. for Jefferson County to $4.11/bu. for Monroe County. Total costs per acre (operating plus fixed) ranged from $471.80/ac for Jefferson County to $944.48/ac for Woodruff County, and total costs per bushel ranged from $2.62/bu. for Jefferson County to $5.03/bu. for Monroe County. Returns above operating costs ranged from $209.13/ac for Lincoln County to $532.19/ac for Jefferson County, and returns above total costs ranged from $47.63/ac for Woodruff County to $448.71/ac for Jefferson 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 2019 RRVP was 183 bu./ac but ranged from 164 bu./ac for Desha County to 214 bu./ac for Craighead County. An Arkansas average long-grain cash price of $5.01/bu. was estimated using United States Department of Agriculture-National Agricultural Statistics Service (USDA-NASS, 2019) 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 and a standard milling yield of 55/70 for long-grain rice. Broken rice was assumed to have 65% of whole- grain price value. If milling yield was higher than the standard, a premium was made while a discount was given for milling less than the standard. Estimated long-grain prices adjusted for milling yield varied from $4.69/bu. in Crittenden County to $5.40/bu. in Desha County (Table 7).

The average operating expense for the 15 RRVP fields was $584.93/ac (Table 7). Fertilizers and nutrients expenses accounted for the largest share of operating expenses on average (19.6%) followed by post-harvest expenses (18.9%), seed (18.7%), and chemicals (12.7%). Although seed's share of operating expenses was 18.7% across the 15 fields, it's average cost and share of operating expenses varied depending on whether a Clearfield hybrid was used ($162.00/ac; 26.2% of operating expenses), a non-Clearfield hybrid was used ($147.85/ac; 23.6% of operating expenses), or a non-Clearfield non-hybrid (pure-line) variety was used ($41.99/ac; 7.9% of operating expenses). None of the 15 RRVP fields in 2019 planted a Clearfield non-hybrid (pure-line) variety.

The average return above operating expenses for the 15 fields was $353.68/ac and ranged from $209.13/ac for Lincoln County to $532.19/ac for Jefferson County. The average return above total specified expenses for the 15 fields was $236.18/ac and ranged from $47.63/ac for Woodruff County to $448.71/ac for Jefferson 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 traditionally contoured Arkansas County field was located just west of Stuttgart on Dewitt silt loam soil. The field consisted of 60 acres and the previous crop grown on the field was soybean. The variety chosen was Diamond treated with CruiserMaxx Rice seed treatment and drill seeded. The seeding rate was 75 lb/ac planted on 28 April. Emergence was observed on 13 May with a stand count of 14 plants/ft^2. No tillage practices were used for spring field preparation. According to the soil test a 0-50-60-10 lb/ac (N-P_2O_5-K_2O-Zn) was applied. Glyphosate, Command, and League herbicides were applied at planting on 30 April. Facet was applied as a postemergence herbicide on 28 May. Using the N-STaR recommendation, N fertilizer in the form of urea plus an approved NBPT was applied at 170 lb/ac on 29 May. Multiple inlet rice irrigation was utilized to achieve a more efficient permanent flood. Midseason nitrogen as urea was applied according to GreenSeeker response index on 26 June at a rate of 100 lb/ac. An adequate flood was maintained throughout the growing season. The field was checked weekly for diseases and no fungicide application was required based on field evaluations. Rice stink bugs reached threshold levels and lambda-cyhalothrin was applied on July 3. The field was harvested on 27 September yielding 184 bu./ac and a milling yield of 52/69. The average harvest moisture was 16%. Total irrigation was 33.5 ac-in./ac and total rainfall was 21.48 in.

Chicot County

The 57-acre zero-grade row rice field was located north of Lake Village on a Perry clay soil. No spring tillage practices were utilized and soybean was the previous crop. RiceTec Gemini 214 CL treated with the company's standard seed treatment including NipsIt INSIDE was drill-seeded on 4 April at 23 lb/ac. Preplant fertilizer of 18-46-0 lb/ac (N-P_2O_5-K_2O) was applied on April 4. Command and League herbicides were applied at planting. Field emergence was recorded on 29 April with a stand density of 6.7 plants/ft^2. Clearpath was applied as a postemergence herbicide on 23 May. Based on N-STaR results and current recommendations for N management in furrow-irrigated rice, N fertilizer in the form of urea plus NBPT was applied at 130 lb/ac on 18 May. A second N application of 130 lb/ac was applied 30 May. A third N application of 130 lb/ac was applied 7 June. Intermittent flushing was maintained throughout the growing season as a practice with row rice production. Based on GreenSeeker response index during midseason growth stages, N level was sufficient. Late-boot N was applied as urea on 15 July as urea at 70 lb/ac. The field was checked weekly for diseases and based on field evaluations no fungicide application was required. Stink bugs reached threshold levels and on 1 August lambda-cyhalothrin was applied. The field was harvested 12 September with a yield of 187 bu./ac and a milling yield of 58/73. The harvest moisture was 20%. Irrigation amount totaled 36 ac-in./ac and total rainfall was 26.5 in.

Craighead County

The furrow-irrigated Craighead County field was located east of Bay. The soil classification was a combination of Mhoon and Dundee fine sandy loams and Roellen silty clay loam. The field was 68 acres and the previous crop grown was soybean. A no-till system on 38-in. beds from the previous soybean crop was used. A burndown herbicide tank mix of RoundUp Pro Max plus 2,4-D and FirstShot was applied in the spring prior to planting. Based on soil test analysis, a pre-plant fertilizer was applied at 16-42-120 lb/ac ($N-P_2O_5-K_2O$). The hybrid RT XP753 with the company's standard seed treatment including NipsIt INSIDE insecticide was drill-seeded at 25 lb/ac on 30 April. A preemergence tank mix of Command and Facet L was applied on 3 May. Rice emergence was observed on 15 May with a stand count of 5.7 plants/ft^2. An overlapping residual herbicide tank mix application of Prowl H_2O and Command was made on 27 May providing good control of weeds. A final herbicide application of Sharpen and crop oil concentrate was made on 4 June. Using the N-STaR results and current recommendations for furrow-irrigated rice, urea plus an approved NBPT product was applied at 180 lb/ac on 5 June and again on 13 June at the same rate. Extension's standard for sufficient nitrogen levels for both midseason and late boot stages was achieved with no additional nitrogen fertilizer. This was unanticipated but was verified weekly with GreenSeeker technology until the onset of head emergence. Irrigation flushes began with the first urea application and, in the absence of rain, were repeated every 3 days, increasing to every 2 days at grain fill. The rice stink bug population was monitored each week after 75% heading until 60% hard dough. The field was checked weekly for diseases. No insecticide or fungicide treatments were required. The rice was harvested on 14 September yielding 214 bu./ac. The milling yield was 45/69. The average harvest moisture was 12.5%. Total irrigation for the season was 27.6 ac-in./ac. Rainfall was 14.84 in.

Crittenden County

The precision-graded Crittenden County field was located 8 miles west of West Memphis and south of Interstate 40 on a Sharky silty clay soil. The field was 50 acres and the previous crop grown was soybean. Conventional tillage practices were used for field preparation in the spring. Based on soil test analysis, no pre-plant fertilizer was applied. The variety Diamond with Apron XL seed treatment was drill-seeded at 84 lb/ac on 8 May. A preemergence application of Command herbicide was made at planting. Rice emergence was observed on 21 May with a stand count of 16.5 plants/ft^2. A postemergence herbicide tank mix of Facet L, Command, Aim, and crop oil concentrate was applied on 30 May providing good weed control. Using the N-STaR recommendation, N fertilizer as urea plus an approved NBPT product was applied preflood on 14 June at 175 lb/ac. A permanent flood was subsequently established within 5 days. The MIRI system was utilized for more efficient flood management. On 5 July, a midseason N fertilizer application of 100 lb/ac of urea was made based on N level monitoring utilizing GreenSeeker technology. An additional corrective N fertilizer application of 100 lb/ac of urea was made 12 July on a 15-acre area where earlier precision grading required a deeper cut that significantly reduced the soil nitrogen level. The rice stink bug population was monitored each week after 75% heading until 60% hard dough. The field was checked weekly for diseases. No insecticide or fungicide treatments were required. The rice was harvested on 23 September yielding 174 bu./ac. The milling yield was 63/69. The average harvest moisture was 16.4%. Total irrigation for the season was 18.2 ac-in./ac. Rainfall was 19.17 in.

Desha County

The 75.9-acre contour-levee field was located east of Tiller on Sharkey and Desha clay soil. No tillage practices were performed and the previous crop was rice. According to the soil test a pre-plant fertilizer of 18-46-0 lb/ac ($N-P_2O_5-K_2O$) was applied in the spring with an airplane. The hybrid RT CLXL745 treated with the company's standard seed treatment including NipsIt INSIDE was drill-seeded at 24 lb/ac on 25 May. Command, Sharpen, and Glyphosate were applied on 28 April as preemergence and burndown herbicides. Emergence was observed on 10 June with 3.7 plants/ft^2. Regiment and RiceStar herbicides were applied postemergence on 29 June. Nitrogen fertilizer as urea plus an approved NBPT was applied at 300 lb/ac on 2 July according to the N-STaR recommendation. Multiple inlet rice irrigation was utilized to achieve a more efficient permanent flood. Based on GreenSeeker response index during midseason growth stages, midseason N levels were sufficient. Late-boot N was applied as urea at 70 lb/ac on 29 July. The field was checked weekly for diseases and due to a history of smut a fungicide application was applied 1 August. Stink bugs reached threshold levels and lambda-cyhalothrin insecticide was applied on 21 August. The field was harvested on 3 October yielding 164 bu./ac with a milling yield of 64/73. The average harvest moisture was 15%. The irrigation amount was 28 ac-in./ac and the total rainfall was 26.5 in.

Jackson County

The precision-graded Jackson County field was 2 miles west of Newport on Amagon, Forestdale, and Dexter silt loam soils. The field was 20 acres and the previous crop grown on the field was rice. Conventional tillage practices were used for field preparation in the spring after 1 ton of chicken litter was applied. Based on a subsequent soil test analysis, additional mixed fertilizer was also applied on 6 June at 0-40-60 lb/ac ($N-P_2O_5-K_2O$). The variety Diamond with CruiserMaxx Rice seed treatment was drill-seeded at 70 lb/ac on 24 April. A preemergence application of Command herbicide was made at planting. Rice emergence was observed on 8 May with a stand count of 15 plants/ft^2. A postemergence tank mix application of Prize (quinclorac) plus Prowl H_2O was made on 23 May followed by Propanil plus Permit Plus on 30 May. Good weed control was achieved. Using the N-STaR recommendation, N fertilizer as urea plus an approved NBPT product was applied preflood on 6 June at 165 lb/ac. A permanent flood was subsequently established within 2 days. Multiple inlet rice irrigation was utilized for a more efficient flood management. On 22 June, a Ricestar application was made with a Mud Master self-propelled sprayer on 1.2 acres to control a small area of grass escapes. A midseason N fertilizer application of 100 lb/ac of urea was made on 27 June based on N level monitoring utilizing GreenSeeker technology. The field was checked weekly for diseases. On 18 July, a fungicide tank mix of Tilt and Quadris was applied as a control of existing sheath blight and to help prevent false smut. The rice stink bug population was monitored each week after 75% heading until 60% hard dough. Rice stink bugs reached treatment threshold and an application of lambda-cyhalothrin was made on 2 August. The rice was harvested on 10 September yielding 166 bu./ac. The milling yield was 58/73. The average harvest moisture was 15%. Total irrigation for the season was 29.5 ac-in./ac. Rainfall was 16.29 in.

Jefferson County

The 30.4-acre conventional-levee field was located just north of Cornerstone and south of Altheimer. The soil classification consisted of Portland Clay and Herbert silt loam soil. The previous crop grown was soybean. The variety Diamond treated with CruiserMaxx Rice and zinc seed treatments was drill-seeded at 80 lb/ac on 4 April. No pre-plant fertilizer was necessary according to soil test results. The herbicides Glyphosate, Command, and First Rate were applied at planting. Emergence was observed on 26 May at 22 plants/ft^2. SuperWham and RiceOne herbicides were applied 30 April. Nitrogen fertilizer in the form of urea was applied at 225 lb/ac with an approved NBPT according to N-STaR recommendations. Multiple inlet rice irrigation was utilized to achieve a more efficient permanent flood. Based on GreenSeeker response index during midseason growth stages, the response index was less than 1.15 and no midseason N fertilizer was recommended. The field was checked weekly for diseases and no fungicide application was required based on field evaluations. Rice stink bugs reached threshold levels and were treated with lambda-cyhalothrin on 8 July. The field was harvested on 19 August yielding 180 bu./ac with a milling yield of 57/71. The average harvest moisture was 18%. Total irrigation was 8.2 ac-in./ac and total rainfall was 24.45 in.

Lawrence County

The precision-graded Lawrence County field was located southeast of Hoxie on Jackport silty clay soil. The field was 18 acres and the previous crop grown was rice. Spring conventional tillage practices were used for field preparation and a pre-plant fertilizer based on soil test analysis was applied 10 April at 0-60-0 lb/ac ($N-P_2O_5-K_2O$). On 11 April, the hybrid RT XP753 with the company's standard seed treatment including NipsIt INSIDE insecticide was drill-seeded at 32 lb/ac. Rice emergence was observed on 30 April and consisted of 8.7 plants/ft^2. A preemergence application of Command herbicide was made at planting on 11 April and was followed by a postemergence application on 14 May of Command plus Regiment and Phase II surfactant. Good weed control was achieved. Using the N-STaR recommendation, N fertilizer as urea plus an approved NBPT product was applied preflood at 300 lb/ac on 28 May. The permanent flood was established within 4 days. Flood levels were maintained sufficiently throughout the season. GreenSeeker technology was utilized weekly during midseason growth stages to monitor N levels. Streaking of the N application became apparent and a corrective N application of 100 lb/ac of urea was made on 18 June. This was followed by a late boot N fertilizer application of urea at 65 lb/ac on 12 July. The field was checked weekly for diseases. Based on field evaluations, no fungicide application was required. The rice stink bug population was monitored each week after 75% heading until 60% hard dough. Lambda-cyhalothrin was applied on 28 July. The field was harvested on 10 September yielding 210 bu./ac. Moisture at harvest was 17%. The milling yield was 61/71. Total irrigation was 30 ac-in./ac and total rainfall for the season was 14.23 in.

Lee County

The 106.5-acre field was located just west of Moro with the soil classification being Henry silt loam soil. Soybean was the previous crop grown on the field. Conventional tillage practices were performed on the contour-levee field. A pre-plant fertilizer blend of 0-30-90-10 lb/ac ($N-P_2O_5-K_2O-Zn$) was applied according to the soil sample analysis. The variety Diamond treated with CruiserMaxx Rice plus zinc seed treatment was broadcast at 80 lb/ac on 29 April. Command and Sharpen were applied on 30 April as burndown and preemergence herbicides. Emergence was observed on 10 May with 15 plants/ft^2. Facet L and Permit Plus were applied on 2 May as postemergence herbicides. Based on N-STaR recommendations, N fertilizer as urea plus an approved NBPT product was applied at 260 lb/ac on 5 June. A minimal flood was maintained throughout the growing season with MIRI. Based on GreenSeeker response index during midseason growth stages, the response index exceeded 1.15 and midseason N fertilizer was applied as urea at 100 lb/ac on 2 July. The field was checked weekly for diseases and no fungicide application was required based on field evaluations. The field was harvested on 25 September with a yield of 181 bu./ac and a milling yield of 57/71. The average harvest moisture was 12%. Total irrigation was 32 ac-in./ac and total rainfall was 13.38 inches.

Lincoln County

The 38-acre zero-grade field was located just north of Star City on a Perry clay soil. The previous crop was soybean. Conventional spring tillage practices were performed on the field. The hybrid RT Gemini 214 CL treated with the company's standard seed treatment including NipsIt INSIDE was drill-seeded on 4 June. The seeding rate was 25 lb/ac. Glyphosate, Command, and League herbicides were applied at planting. The rice emerged on 9 June at 7.1 plants/ft^2. On 21 June, RiceBeaux and Facet L were applied as postemergence herbicides. Using the N-STaR recommendation, N fertilizer as urea with an approved NBPT was applied at 275 lb/ac on 6 June. According to the soil test, a preplant fertilizer of 18-46-0 lb/ac (N-P_2O_5-K_2O) was applied with the preflood N. Based on GreenSeeker response index during midseason growth stages, N levels were adequate. The late boot N fertilizer application was made on 10 July as urea at 75 lb/ac. The field was checked weekly for diseases and no fungicide application was required based on field evaluations. The field was harvested very late on November 20 yielding 171 bu./ac with a milling yield of 54/69. The average harvest moisture was 15.3%. Total irrigation water use was 32 ac-in./ac and total rainfall was 10.6 in.

Lonoke County

The 71.7-acre contour field was located north of Lonoke on a Callaway silt loam soil. Spring conventional tillage practices were used and pre-plant fertilizer was applied at 0-40-60 lb/ac (N-P_2O_5-K_2O) according to the soil test. The hybrid RT XP753 treated with the company's standard seed treatment including NipsIt INSIDE was drill-seeded at 20 lb/ac on 28 April. Roundup and Command were applied on 28 April as burndown and preemergence herbicides. Stand emergence was observed on 10 May with 4.3 plants/ft^2. Facet L, Prowl, and RiceBeaux were applied as postemergence herbicides on 21 May. Nitrogen fertilizer in the form of urea with NBPT was applied 2 June according to the N-STaR recommendation. Multiple inlet rice irrigation was utilized to achieve a more efficient permanent flood. Based on GreenSeeker response index during midseason growth stages, N levels were adequate. The late-boot N fertilizer application was made on 13 July at 70 lb/ac. The field was harvested on 30 September yielding 195 bu./ac and a milling yield of 55/70. Total irrigation water use was 9.35 ac-in./ac and total rainfall was 21.5 inches.

Monroe County

The 82.8-acre contour field was located southeast of Garrett Grove. The soil classification was Dundee and Foley Calhoun Bonn. Spring conventional tillage practices were used for field preparation and based on soil analysis a 0-0-60-10 lb/ac (N-P_2O_5-K_2O-Zn) was applied. Top Choice fertilizer was applied in the spring at 500 lb/ac. The hybrid RT XP753 treated with the company's standard seed treatment including NipsIt INSIDE was drill-seeded at 22 lb/ac on 28 April. Command herbicide was applied at planting. Emergence was observed on 11 May with 7.3 plants/ft^2. SuperWham, Prowl, and Permit were applied as postemergence herbicides on 12 May. Regiment and Facet L herbicides were applied 28 May. Using the N-STaR recommendation, N fertilizer as urea was applied at 250 lb/ac on 4 June. Based on GreenSeeker response index during midseason growth stages, N levels were adequate. Late-boot N fertilizer was applied as urea at 70 lb/ac on 2 July. Stink bugs also reached threshold levels and lambda-cyhalothrin was applied on 6 August. The field was harvested 14 September yielding 175 bu./ac. The milling yield was 60/74 and the average harvest moisture was 17%. Total irrigation for the season was 34 ac-in./ac and total rainfall was 19.25 inches.

Randolph County

The precision-graded Randolph County field was located 6 miles northeast of Pocahontas near the Fourche River on a Hontas silt loam soil. This was the 4th rice crop following precision-grading work. The field was 42 acres and the previous crop grown was rice. An application of chicken litter at 2 tons/ac was made in the spring and conventional tillage practices were used for field preparation. A mixed fertilizer based on soil test analysis was applied at 0-0-60-5 lb/ac (N-P_2O_5-K_2O-Zn). The hybrid RT CLXP4534 treated with the company's standard seed treatment including NipsIt INSIDE was drill-seeded at 22 lb/ac on 9 April. Rice emergence was observed on 6 May. The stand count was not as uniform as desired but keeping the stand was determined to be the best option. Command was applied as a preemergence herbicide on 10 April followed by a postemergence application of Clearpath and crop oil concentrate on 14 May providing good weed control. Based on N-STaR recommendations, a pre-flood application of urea plus an approved NBPT product was made on 2 June at 165 lb/ac. Surface water was utilized to achieve a permanent flood. Extension's standard for sufficient midseason N levels was achieved with the pre-flood N rate and verified with GreenSeeker technology. A late boot N fertilizer application of urea was made at 65 lb/ac on 10 July. The rice stink bug population exceeded treatment threshold and Mustang Maxx was applied on 18 July. The field was checked weekly for diseases and no fungicide treatments were required. The rice was harvested on 3 September yielding 181 bu./ac. The milling yield was 63/71. The average harvest moisture was 16.3%. Total irrigation for the season was 16.8 ac-in./ac. Rainfall was 18.23 inches.

White County

The precision-graded White County field was located south of Kensett on Calhoun and Callaway silt loam soils. The field was 74 acres and the previous crop grown was soybean. Spring conventional tillage practices were used for field preparation and a pre-plant fertilizer based on soil test analysis was applied at 0-47-127-3 lb/ac (N-P_2O_5-K_2O-Zn). A burndown herbicide application of glyphosate was made on 18 May. On 20 May, the hybrid RT XP753 with the company's standard seed treatment including NipsIt INSIDE insecticide was drill-seeded on 50 acres at 24 lb/ac before planting was halted by rain. Planting resumed on 25 May with the same cultivar and rate on the remaining 24 acres. Rice emergence on the initial 50 acres was observed on 27 May and on the remaining 24 acres on 3 June. The stand count consisted of 7.6 plants/ft^2 and 6.1 plants/ft^2, respectively. An application of RiceOne (clomazone + pendimethalin premix) plus Prowl H_2O herbicides was made on 28 May followed by a postemergence application of RiceBeaux on 21 June providing good control of weeds. Using the N-STaR recommendation, N fertilizer as urea plus an approved NBPT product was applied preflood at 240 lb/ac on 21 June. A permanent flood of reservoir water was established within 4 days. Flood levels were maintained sufficiently throughout the season. GreenSeeker technology was utilized weekly during midseason growth stages and no midseason N was recommended. A late boot N fertilizer application of urea was made at 65 lb/ac on 2 August. Based on evaluating the field weekly for diseases, no fungicide application was required. The rice stink bug population was monitored each week after 75% heading until 60% hard dough. Rice stink bugs reached the threshold for treatment prompting an application of Lambda-Cy on 12 August. The field was harvested on 27 September yielding 175 bu./ac. Moisture at harvest was 16.5%. Total irrigation was 30 ac-in./ac and total rainfall for the season was 15.5 inches.

Woodruff County

The precision-graded Woodruff County field was located 3 miles south of McCrory on Wiville fine sandy loam and Tuckerman loam soils. The field was 36 acres and the previous crop grown was soybean. Spring conventional tillage practices were used for field preparation and a pre-plant fertilizer based on soil test analysis was applied at 0-60-90-2 lb/ac (N-P_2O_5-K_2O-Zn). On 24 April, the variety Diamond with CruiserMaxx Rice seed treatment was drill-seeded at 70 lb/ac on 12 acres before a breakdown occurred with the grain drill. The remaining 24 acres was broadcast that day with the same cultivar and seed treatment at 112.5 lb/ac and covered with a harrow. Rice emergence was observed on 2 May and consisted of 26.6 plants/ft² drilled and 27 plants/ft² broadcast. A preemergence application of Command herbicide was made on 24 April followed by a postemergence tank mix herbicide application of Super Wham, Permit, Facet L, and crop oil concentrate on 30 May. On 31 May, the N-STaR recommendation of 240 lb/ac of urea plus an approved NBPT product was applied. Flood-up occurred over the next 7 days using the MIRI system. GreenSeeker technology was utilized during mid-season growth stages to monitor the crop's N level. The planned midseason N application was made with urea at 100 lb/ac on 27 June. The field was checked weekly for diseases. On 20 July, Quilt Xcel was applied for sheath blight and false smut control. The rice stink bug population was monitored each week after 75% heading until 60% hard dough. No insecticide treatments were made. The field was harvested on 14 September. The yield was 194 bu./ac. Moisture at harvest was 15%. The milling yield was 57/71. Total irrigation was 68.7 ac-in./ac and total rainfall for the season was 9.95 inches.

Practical Applications

Data collected from the 2019 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

This research was supported the Arkansas Rice Check-Off funds administered by the Arkansas Rice Research and Promotion Board. Additional support was provided by the University of Arkansas System Division of Agriculture.

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Table 1. Agronomic information for fields enrolled in the 2019 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
		acres		lb/ac	plants/ft^2				bu./ac	%HR/%TR	%
Arkansas	Diamond	60	Soybean	65	14	28-Apr	13-May	27-Oct	184	52/69	16%
Chicot	RT Gemini 214 CL	57	Soybean	23	6	3-Apr	29-May	12-Aug	187	53/58	20%
Craighead	RT XP753	68	Soybean	25	6	30-Apr	15-May	14-Sep	214	45/69	13%
Crittenden	Diamond	50	Soybean	84	17	8-May	21-May	23-Sep	174	63/69	16%
Desha	RT CLXL745	76	Rice	24	4	25-May	10-June	3-Oct	164	64/73	15%
Jackson	Diamond	20	Rice	70	15	24-Apr	5-May	10-Sep	166	58/73	15%
Jefferson	Diamond	30	Soybean	80	22	3-Apr	26-Apr	19-Aug	180	57/71	18%
Lawrence	RT XP753	18	Rice	32	9	11-Apr	30-Apr	10-Sep	210	61/71	17%
Lee	Diamond	107	Soybean	80	15	29-May	10-May	25-Sep	181	57/71	12%
Lincoln	RT Gemini 214 CL	38	Soybean	25	7	4-June	9-June	11-Nov	171	54/69	15%
Lonoke	RT XP753	72	Soybean	20	4	28-May	10-May	30-Sep	195	55/70	14%
Monroe	RT XL753	83	Corn	22	7	28-Apr	11-May	14-Sep	175	60/74	17%
Randolph	RT CL XP4534	42	Rice	22	5	9-Apr	6-June	3-Sep	181	63/71	16%
White[b]	RT XP753	50	Soybean	24	7.6	20–May	27-May	27-Sep	175	55/71	17%
White[c]	RT XP753	24	Soybean	24	5	25-May	3- June	27-Sep	175	55/71	17%
Woodruff[d]	Diamond	12	Soybean	70	27	24-Apr	2-May	14-Sep	194	57/71	15%
Woodruff[e]	Diamond	24	Soybean	113	27	24-Apr	2-May	14-Sep	194	57/71	15%
Average		**55**	------	[f]	[g]	**4-May**	**16-May**	**20-Sep**	**183**	**57/70**	**16.%**

[a] Milling yield numbers: First number = % Head rice (whole white grains)/Second number = % Total white rice (whole grains + broken grains).

[b] Represents 50 of 74 acres planted in the White County field before rain halted planting.

[c] Represents remaining 24 of 74 acres planted in the White County field after conditions allowed planting to resume.

[d] Represents 12 of 36 acres in the Woodruff County field drill seeded before mechanical failure of grain drill.

[e] Represents remaining 24 of 36 acres in the Woodruff County field broadcast seeded after mechanical failure of grain drill.

[f] Seeding rates averaged 80 lb/ac for conventional cultivars and 24 lb/ac for hybrid cultivars.

[g] Stand density averaged 18 plants/ft^2 for conventional cultivars and 6 plants/ft^2 for hybrid cultivars.

Table 2. Soil test results, fertilization, and soil classification for fields enrolled in the 2019 Rice Research Verification Program.

		Soil Test			Applied Fertilizer			
Field location by county	pH	P	K	Zn	Mixed fertilizer[a] N-P-K-Zn[b]	N-Star urea (46%N) rates and timing[c, d]	Total N rate[e]	Soil classification
	-----------(lb/ac)------------				---------------(lb/ac)--------------		(lb N/ac)	
Arkansas	7.0	64	230	10	0-50-60-10	170-100-0	124	Dewitt silt loam
Chicot	7.0	45	594	3.2	18-46-0-0	390-0-70	212	Perry clay
Craighead	6.3	58	146	1.5	0-42-120-0	180-180-0*	166	Mhoon & Dundee sandy loam
Crittenden	6.4	74	948	7.6	0-0-0-0	175-100-0	173+	Sharkey silty clay
Desha	6.8	19	756	5.9	18-46-0-0	300-0-70	170	Sharkey and Desha clay
Jackson	6.2	31	201	8.2	0-40-60-0	165-100-0	122	Amagon & Forestdale silt
Jefferson	6.9	56	684	6.0	0-0-0-0	225-0-0	103	Portland clay/Herbert silt
Lawrence	7.1	20	326	6.6	0-60-0-0	300-0-65	215+	Jackport silty clay
Lee	7.4	66	182	3.9	0-30-90-10	260-100-50	166	Perry clay
Lincoln	6.6	40	498	4.4	0-60-90-10	240-0-70	195	Callaway silt loam
Lonoke	5.7	24	212	0.8	0-60-90-10	240-70-0	143	Henry silt loam
Monroe	7.0	70	198	5.1	0-0-60-10	250-70-0	147	Foley Cal. Bonn Dundee silt
Randolph	7.0	80	219	7.1	0-0-60-5	164-0-65	105	Hontas silt loam
White	6.6	75	122	2.9	0-47-127-5	240-0-65	140	Calhoun/Calloway silt loam
Woodruff	6.6	30	220	6.2	0-60-90-2	240-100-0	156	Wiville fine sandy loam

[a] Column represents regular pre-plant applications.

[b] N = nitrogen, P = phosphorus, K = potassium, Zn = zinc.

[c] Timing: preflood – midseason – boot. Each field was fertilized according to its Nitrogen Soil Test for Rice (N-STaR) recommendation. The mark (*) denotes an adjusted N-STaR rate and timing for furrow-irrigated rice.

[d] The N-STaR preflood N recommendation in all fields was treated with an approved n-butyl thiophosphoric triamide (NBPT) product to minimize N loss due to ammonia volatilization.

[e] Certain fields received additional seasonal N exceeding the N-Star recommendation by 46 lb due to factors encountered during the season post-flood. This additional N is included in the totals marked (+). Extra N applied 2 weeks or more before flood-up to address nitrogen loss recorded in the Mixed fertilizer column.

Table 3. Herbicide rates and timings for fields enrolled in the 2019 Rice Research Verification Program.

Field location by county	Preemergence herbicide applications	Postemergence herbicide applications
	---------(trade name and product rate/ac)[a]---------	
Arkansas	Glyphosate (1 qt) + Command (12.8 oz) + League (6.4 oz)	Facet L (32 oz) + COC (16 oz)
Chicot	Newpath (4 oz) +Command (12.8 oz) + League (6.4 oz)	Clearpath (0.5 lb) + COC (32 oz)
Craighead	RoundUp Maxx (1 qt) + 2,4-D (24 oz) + First Shot (0.6 oz) fb Command (12.8 oz) + Facet L (22 oz)	Prowl H_2O (33.6 oz) + Command (10 oz) fb Sharpen (1 oz) + COC (20 oz)
Crittenden	Command (24 oz)	Facet L (32 oz) + Aim (1 oz) + Command (8 oz) + COC (6.4 oz)
Desha	Command (21 oz) + Sharpen (2 oz) + Glyphosate (32 oz)	Regiment (0.63 oz) + RiceStar (24 oz) + COC (32 oz)
Jackson	Command (12.8 oz)	Prize (12 oz) + Prowl H_2O (2 pts) fb Propanil (3 qts) + Permit Plus (0.75 oz) fb Ricestar (24 oz) as spot treatment (1.2 acres)
Jefferson	Glyphosate (32 oz) + Command (16 oz) + First Shot (0.5 oz)	SuperWham (3 qts) + Rice One (45 oz) + COC (1 pt)
Lawrence	Command (16 oz)	Command (sequential 6 oz) + Regiment (0.67 oz) + Phase II Surfactant (6.4 oz)
Lee	Command (12.8 oz) + Sharpen (2 oz)	Facet L (32 oz) + Permit Plus (0.75 oz)
Lincoln	Glyphosate (32 oz) + Command (20 oz) + League (6.4 oz)	RiceBeaux (32 oz) + Facet L (32 oz)
Lonoke	Glyphosate (32 oz) fb Roundup (36 oz) + Command (12.8 oz)	Facet L (32 oz) + Prowl (32 oz) + RiceBeaux (3 qts)
Monroe	Command (12.8 oz) fb SuperWham (4 qts) + Permit (1 oz) + Prowl (2.1 pt)	Regiment (0.63 oz) + Facet L (43 oz) + COC (32 oz)
Randolph	Command (12.8 oz)	Clearpath (0.5 lb) + COC (6.4 oz)
White	Glyphosate (48 oz) fb RiceOne (24 oz) + Prowl H_2O (0.9 pt)	RiceBeaux (3 qt)
Woodruff	Glyphosate (32 oz) fb Command (16 oz)	Super Wham (3.5 qt) + Permit (1 oz) + Facet L (32 oz) + COC (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 2019 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[a]	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	CruiserMaxx Rice (7 fl oz)	------	------	------	Lambda-Cyhalothrin (2.5 oz)
Chicot	RTST	------	------	------	Lambda-Cyhalothrin (1.6 oz)
Craighead	RTST	------	------	------	------
Crittenden	Apron XL LS (0.64 oz)	------	------	------	------
Desha	RTST	------	------	------	------
Jackson	CruiserMaxx Rice (7 fl oz)	Tilt (5 oz) + Quadris (8 oz)	------	------	Lambda-Cyhalothrin (2 oz)
Jefferson	CruiserMaxx Rice (7 fl oz)	------	------	------	Lambda-Cyhalothrin (1.8 oz)
Lawrence	RTST	------	------	------	Lambda-Cyhalothrin (3.6 oz)
Lee	CruiserMaxx Rice (7 fl oz)	------	------	------	------
Lincoln	RTST	------	------	------	------
Lonoke	RTST	------	------	------	------
Monroe	RTST	------	------	------	Lambda-Cyhalothrin (2.1 oz)
Randolph	RTST	------	------	------	Mustang Maxx (4 oz)
White	RTST	------	------	------	Lambda-Cyhalothrin (3.7 oz)
Woodruff	CruiserMaxx Rice (7 fl oz)	Quilt Xcel (21 oz)	------	------	------

[a] RTST = RiceTec Seed Treatment is the standard treatment applied to seed by RiceTec, Inc. prior to seed purchase and includes zinc, fungicides, and NipsIt INSIDE insecticide.

Table 5. Rainfall and irrigation information for fields enrolled in the 2019 Rice Research Verification Program.

Field location by county	Rainfall	Irrigation[a]	Rainfall + Irrigation
	(inches)	(acre-inches)	(inches)
Arkansas	33.0	21.5	54.5
Chicot	26.5	36.0	62.5
Craighead	14.8	27.6	42.4
Crittenden	19.2	18.2	37.4
Desha	26.1	30.0*	56.1
Jackson	16.3	29.5	45.8
Jefferson	24.5	8.2	32.7
Lawrence	14.2	30.0*	44.2
Lee	13.4	30.0*	43.4
Lincoln	10.6	34.5	45.1
Lonoke	21.5	9.4	30.9
Monroe	19.3	30.0*	49.3
Randolph	18.2	16.8	35.0
White	15.5	30.0*	45.5
Woodruff	9.9	68.7	78.7
Average[b]	**18.9**	**27.0**	**46.5**

[a] An average established from flow meter data over a period of years was used for several fields not equipped with flow meters to monitor irrigation water use. Irrigation amounts using this calculated average are followed by an asterisk (*).

[b] Average values for Irrigation and Rainfall + Irrigation are only for those fields with measured irrigation amounts and does not include fields where the state average irrigation value of 30.0 acre-inches was used.

Table 6. Operating Costs, Total Costs, and Returns for fields enrolled in the 2019 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	451.74	2.46	446.06	92.12	543.86	353.95	2.96
Chicot	638.43	3.41	360.73	89.30	727.73	271.43	3.89
Craighead	652.56	3.05	351.67	95.06	747.63	256.60	3.49
Crittenden	440.08	2.53	459.98	101.74	541.81	358.25	3.11
Desha	607.35	3.70	278.56	123.36	730.71	155.20	4.46
Jackson	641.89	3.87	228.25	119.20	761.09	109.06	4.58
Jefferson	388.32	2.16	532.19	83.48	471.80	448.71	2.62
Lawrence	693.69	3.30	402.64	125.59	819.28	277.05	3.90
Lee	483.65	2.67	441.98	113.42	597.07	328.55	3.30
Lincoln	634.36	3.71	209.13	143.41	777.77	65.72	4.55
Lonoke	502.48	2.58	474.47	76.59	579.07	397.88	2.97
Monroe	719.34	4.11	216.18	160.23	879.57	55.95	5.03
Randolph	590.44	3.26	364.15	123.92	714.36	240.24	3.95
White	561.85	3.21	314.90	138.39	700.24	176.51	4.00
Woodruff	767.80	3.96	224.31	176.68	944.48	47.63	4.87
Average	**584.93**	**3.20**	**353.68**	**117.50**	**702.43**	**236.18**	**3.85**

Table 7. Summary of Revenue and Expenses per Acre for fields enrolled in the 2019 Rice Research Verification Program.

Receipts	**Arkansas**	**Chicot**	**Craighead**	**Crittenden**	**Desha**	**Jackson**	**Jefferson**	**Lawrence**
Yield (bu.)	184	187	214	174	164	166	180	210
Price Received	4.88	5.34	4.69	5.17	5.40	5.24	5.11	5.22
Total Crop Revenue	**897.80**	**999.16**	**1004.23**	**900.06**	**885.91**	**870.15**	**920.51**	**1096.34**
Operating Expenses								
Seed	36.40	167.90	150.25	29.99	149.76	39.20	48.64	192.32
Fertilizers & Nutrients	97.02	135.88	120.99	87.69	121.43	125.78	59.51	119.03
Chemicals	73.59	68.30	68.42	50.24	79.14	127.90	76.29	26.21
Custom Applications	37.60	55.20	52.30	45.50	74.40	84.20	34.00	71.00
Diesel Fuel	13.30	11.11	10.22	16.38	14.13	17.16	14.14	17.92
Repairs & Maintenance	20.44	19.02	19.78	22.21	27.53	26.43	18.97	27.36
Irrigation Energy Costs	43.47	47.42	81.50	53.74	18.67	87.11	10.80	88.58
Labor, Field Activities	9.06	6.67	5.95	9.16	9.02	8.24	9.16	8.67
Other Inputs & Fees, Pre-harvest	9.82	14.07	14.01	20.17	14.31	25.70	8.19	15.87
Post-harvest Expenses	111.04	112.85	129.15	105.01	98.97	100.18	108.63	126.74
Total Operating Expenses	**451.74**	**638.43**	**652.56**	**440.08**	**607.35**	**641.89**	**388.32**	**693.69**
Returns to Operating Expenses	**446.06**	**360.73**	**351.67**	**459.98**	**278.56**	**228.25**	**532.19**	**402.64**
Capital Recovery & Fixed Costs	92.12	89.30	95.06	101.74	123.36	119.20	83.48	125.59
Total Specified Expenses[a]	**543.86**	**727.73**	**747.63**	**541.81**	**730.71**	**761.09**	**471.80**	**819.28**
Returns to Specified Expenses	**353.95**	**271.43**	**256.60**	**358.25**	**155.20**	**109.06**	**448.71**	**277.05**
Operating Expenses/Yield Unit	2.46	3.41	3.05	2.53	3.70	3.87	2.16	3.30
Total Expenses/Yield Unit	2.96	3.89	3.49	3.11	4.46	4.58	2.62	3.90

Table 7. Continued.

Receipts	**Lee**	**Lincoln**	**Lonoke**	**Monroe**	**Randolph**	**White**	**Woodruff**	**Average**
Yield (bu.)	181	171	195	175	181	175	194	**183**
Price Received	5.11	4.93	5.01	5.35	5.27	5.01[b]	5.11	**5.12**
Total Crop Revenue	**925.63**	**843.49**	**976.95**	**935.52**	**954.59**	**876.75**	**992.11**	**938.61**
Operating Expenses								
Seed	44.80	182.50	120.20	132.22	147.84	144.24	52.93	109.28
Fertilizers & Nutrients	116.44	128.33	95.44	131.78	156.08	110.69	109.43	114.37
Chemicals	69.16	71.20	73.50	125.20	42.56	47.55	113.73	74.20
Custom Applications	36.80	58.00	35.20	44.00	52.62	65.70	74.20	54.71
Diesel Fuel	19.56	23.88	13.35	24.97	19.28	17.84	20.95	16.95
Repairs & Maintenance	23.41	29.92	16.84	30.45	27.96	30.94	36.24	25.17
Irrigation Energy Costs	42.15	8.85	12.32	94.49	9.80	17.50	202.86	54.62
Labor, Field Activities	11.37	13.56	6.96	13.49	11.49	8.86	11.78	9.56
Other Inputs & Fees, Pre-harvest	10.72	14.92	11.00	17.13	13.58	12.91	28.62	15.40
Post-harvest Expenses	109.23	103.20	117.68	105.61	109.23	105.61	117.08	110.68
Total Operating Expenses	**483.65**	**634.36**	**502.48**	**719.34**	**590.44**	**561.85**	**767.80**	**584.93**
Returns to Operating Expenses	**441.98**	**209.13**	**474.47**	**216.18**	**364.15**	**314.90**	**224.31**	**353.68**
Capital Recovery & Fixed Costs	113.42	143.41	76.59	160.23	123.92	138.39	176.68	117.50
Total Specified Expenses[c]	**597.07**	**777.77**	**579.07**	**879.57**	**714.36**	**700.24**	**944.48**	**702.43**
Returns to Specified Expenses	**328.55**	**65.72**	**397.88**	**55.95**	**240.24**	**176.51**	**47.63**	**236.18**
Operating Expenses/Yield Unit	2.67	3.71	2.58	4.11	3.26	3.21	3.96	3.20
Total Expenses/Yield Unit	3.30	4.55	2.97	5.03	3.95	4.00	4.87	3.85

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

[b] The White County RRVP field did not have a milling yield sample collected.
The average price of $5.01/bu. was used for White County.

[c] 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 2019 Rice Research Verification Program.

County	Rice type	Seed	Fertilizers and nutrients	Herbicides	Insecticides	Fungicides and other inputs	Diesel Fuel	Irrigation energy costs
Arkansas	Diamond	36.40	97.02	68.86	4.73	---	13.30	43.47
Chicot	RT Gemini 214 CL	167.90	135.88	65.28	3.02	---	11.11	47.42
Craighead	RT XP753	150.25	120.99	68.42	---	---	10.22	81.50
Crittenden	Diamond	29.99	87.69	50.24	---	---	16.38	53.74
Desha	RT CLXL745	149.76	121.43	70.67	3.97	4.50	14.13	18.67
Jackson	Diamond	39.20	125.78	105.73	3.78	18.39	17.16	87.11
Jefferson	Diamond	48.64	59.51	72.21	3.40	0.68	14.14	10.80
Lawrence	RT XP753	192.32	119.03	19.41	6.80	---	17.92	88.58
Lee	Diamond	44.80	116.44	69.16	---	---	19.56	42.15
Lincoln	RT Gemini 214 CL	182.50	128.33	71.20	---	---	23.88	8.85
Lonoke	RT XP753	120.20	95.44	73.50	---	---	13.35	12.32
Monroe	RT XP753	132.22	131.78	121.23	3.97	---	24.97	94.49
Randolph	RT CLXP4534	147.84	156.08	37.20	5.36	---	19.28	9.80
White	RT XP753	144.24	110.69	40.63	6.92	---	17.84	17.50
Woodruff	Diamond	52.93	109.43	93.22	---	20.51	20.95	202.86
Average	**---**	**109.28**	**114.37**	**68.46**	**4.66**	**11.02**	**16.95**	**54.62**

Molecular Analysis to Track Introgression of the *Pi40* Gene in Elite Breeding Materials

V.A. Boyett,[1] V.I. Thompson,[1] K.A.K. Moldenhauer,[1] J. Xue,[1] D.K.A. Wisdom,[1] D.L. McCarty,[1] and C.H. Northcutt[1]

Abstract

In 2019 the major project reported here involved the analysis of rice blast disease resistance conferred by the gene *Pi40*. We also performed genetic analysis on 10 major projects for rice breeding involving DNA marker-assisted selection (MAS) for the important traits of cooking quality, aroma, rice blast disease resistance, plant height, leaf texture, and the herbicide resistance systems Clearfield and Provisia at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC), near Stuttgart, Arkansas. Three smaller projects were conducted for the breeding programs as well. The Molecular Genetics lab screened 4663 test samples with up to 24 markers. The rice molecular analysis projects included parental materials, male sterile and restorer lines, selected F_1 hybrid lines, and early and advanced generations of conventional breeding materials currently in development. In total, the lab generated 51,701 data points for 7 clients. The work was accomplished using 53 DNA template plates, 577 PCR plates, 118 runs on the ABI 3500xL to analyze simple sequence repeat (SSR) markers, and 218 PACE runs to analyze single nucleotide polymorphism (SNP) markers. In 2018 a line from the International Rice Research Institute (IRRI) which has the rice blast resistance gene *Pi40* was crossed with some elite lines in the long-grain breeding program in order to introduce this powerful resistance gene into breeding materials with agronomic traits preferred by Arkansas farmers. The crosses resulted in 4 F_2 populations grown in the field in 2019. A total of 880 plants was screened with 24 markers, with 14 of them linked to 6 blast resistance genes. Through this analysis, it was determined that the IRRI line had the genes *Pi-b* and *Pi-ta* in addition to the *Pi40* gene. The Arkansas parents of two of the populations also had *Pi-ta* and *Pi-k^h*. Analysis of the progeny revealed that approximately 25% of the plants had inherited the *Pi40* gene. Molecular analysis was essential in determining the total rice blast disease resistance potential for the progeny so that selections could be made to promote further advancement in the program.

Introduction

Much of the effort over the last 19 years has been devoted to the genotypic characterization of parental lines and progeny in new long-grain cultivar development. One of the major goals of rice breeding is to increase yields, which can be helped by incorporating genetic resistance to rice blast disease. The pathogenicity of different blast races varies greatly and there is always a possibility that the current resistance genes in use can be overcome, leading to a breakdown in resistance (Jeung et al., 2007). When developing new cultivars, it is important to include new resistance genes to achieve broad-spectrum and durable disease resistance (Jeung et al., 2007; Beşer et al., 2016).

One resistance gene, *Pi40*, exhibits broad-spectrum resistance to blast races (Jeung et al., 2007; Beşer et al., 2016). Originating from a wild Australian rice species, the gene had been incorporated into germplasm at the International Rice Research Institute (IRRI). One of the IRRI lines containing *Pi40* was used as a parent in the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC), long-grain breeding program to develop elite cultivars with improved rice blast disease resistance, good cooking quality and plant type.

Jeung et al., 2007 identified molecular markers that could be used to determine the presence of *Pi40*, finding that the locus-specific marker 9871.T7E2b was completely linked to the gene. Beşer et al., 2016 used this same marker successfully in a marker-assisted introgression study to incorporate the *Pi40* gene into elite rice cultivars in Turkey, proving that the marker has a practical application as well.

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 improved rice blast disease resistance. The goals include (i) characterizing parental materials on a molecular level for important agronomic traits and purity, (ii) performing DNA marker-assisted selection (MAS) of progeny to confirm identity and track gene introgression, and (iii) ensuring seed quality and uniformity by eliminating off types.

Procedures

Leaf tissue from individually tagged field plants was collected in manila coin envelopes and kept in plastic bags on ice until placed in storage at the molecular genetics lab. The leaf tissue was stored at -80 °C (-112 °F) until sampled. Total genomic DNA was extracted from the leaves using a Sodium hydroxide/Tween 20 buffer and neutralized with 100mM 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

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[1] Program Associate, Program Technician, Professor, Technical Assistant, Program Associate, Program Associate, and Program Technician, respectively, University of Arkansas System Division of Agriculture Rice Research and Extension Center.

the starting template for simple sequence repeat (SSR) and InDel analysis. For PACE reactions, the DNA plate was diluted 1:5 in water to prepare the PACE reaction template.

Polymerase Chain Reaction (PCR) of the *Pi40* gene-specific marker 9871.T7E2b was conducted in a Mastercycler Pro S thermal cycler (Eppendorf North America, Inc., Westbury, N.Y.) for 35 cycles of a traditional 3-step PCR protocol. The PCR products were resolved using capillary electrophoresis on an Advanced Analytical Fragment Analyzer and data were analyzed using PROSize 2.0 software (Agilent Technologies, Inc., Santa Clara, Calif.).

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 25-µl reactions and cycling in a Mastercycler Pro S thermal cycler (Eppendorf North America, Inc., Westbury, N.Y.) for 35 cycles of a traditional 3-step PCR protocol. To save on processing and analysis costs, PCR plates were grouped according to allele sizes and dye colors and diluted together with an epMotion 5070 liquid handling robot (Eppendorf North America, Inc., Westbury, N.Y.). The PCR products were resolved using capillary electrophoresis on an ABI 3500xL Genetic Analyzer. 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 2X PACE Master Mix (3c^{r} bioscience, Welwyn Garden City, Hertfordshire, U.K.) + 0.14 µl of the Assay Mix to the wells of a 96-well opaque qPCR plate (LGC Genomics, Beverly, Mass.). The plate was then sealed with qPCR film (LGC Genomics, Beverly, Mass.), and the PACE reactions were cycled in a Mastercycler Pro S thermal cycler (Eppendorf North America, Inc., Westbury, N.Y.) using a 65–57 °C (149–135°F) Touchdown protocol. The plates were then allowed to cool to room temperature prior to reading on a BMG Labtech FLUOstar Omega SNP plate reader (LGC Genomics, Beverly, Mass.). Detected fluorescence was analyzed using KlusterCaller software (LGC Genomics, Beverly, Mass.).

Results and Discussion

Five rice blast resistance genes were evaluated in addition to the *Pi40* gene. Marker analysis indicated that the genes *Pi-i* and *Pi-z* were not present in any of the populations (Data not shown). All 4 populations were segregating for the *Pi-b* gene. Two populations were segregating for the *Pi-ta* gene and 2 populations were homozygous for *Pi-ta*, inheriting the gene from both parents. Two populations were segregating for *Pi-k*^{h}. Molecular analysis was also conducted to assess cooking quality, fertility restoration, plant height, and leaf texture (data not shown).

In the final analysis, 22% of the 248 plants in population 20184008 had *Pi40* (Table 1). Twenty-six percent of plants had *Pi-b* and 99% had *Pi-ta* (Table 1). Sixteen percent of plants had *Pi40* and *Pi-ta* while 6% had all 3 major genes (Table 1). For population 20184009, 42% of 187 plants had *Pi40*, 41% had *Pi-b* and 49% had *Pi-ta* (Table 1). Only 1% had *Pi40* and *Pi-b*, 2% of the plants had *Pi40* and *Pi-ta* while 26% had all 3 genes (Table 1). The *Pi-k* gene was not present in either of these populations (Table 1). Of the 217 plants in population 20184010, 20% had *Pi40*, 29% had *Pi-b*, 34% had *Pi-ta*, and 23% had *Pi-k*^{h} (Table 1). Two percent of the plants had *Pi40* and *Pi-b*, 6% had *Pi40* and *Pi-ta*, while only 1% had all 3 major genes (Table 1). The population 20184012 had 228 plants with only 15% having the *Pi40* gene, 24% had *Pi-b* while 100% had *Pi-ta* (Table 1). Twenty-five percent had the *Pi-k*^{h} gene. Twelve percent had *Pi40* and *Pi-ta* while 3% plants had *Pi40*, *Pi-b*, and *Pi-ta* combined (Table 1).

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, and with multiple rice blast resistance genes present, it would be difficult to determine through a race differential study which genes were responsible for the resistance demonstrated. Compilation of all the marker analyses conducted in the *Pi40* introgression populations enabled the breeder to make selections of plants with enhanced rice blast disease resistance, long-grain cooking quality, and smooth leaves for advancement in the breeding pipeline. 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.

Acknowledgments

This work was supported by funding to the RREC provided by the rice farmers of Arkansas and administered by the Arkansas Rice Research and Promotion Board. The authors also thank the University of Arkansas System Division of Agriculture. The authors thank Dana Curtis and Helen Ellenburg for excellent technical assistance.

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Table 1. Rice blast disease resistance genotypes of select F_2 breeding populations.

Population	20184008	20184009	20184010	20184012
Sample No.	248	187	217	228
% with *Pi40*	22	42	20	15
% with *Pi-b*	26	41	29	24
% with *Pi-ta*	99	49	34	100
% with *Pi-k*^{h}	0	0	23	25
% with *Pi40* + *Pi-b*	0	1	2	0
% with *Pi40* + *Pi-ta*	16	2	6	12
% with *Pi40* + *Pi-b* + *Pi-ta*	6	26	1	3

Differential Response of Arkansas Rice Varieties on High Nighttime Temperature (HNT) Treatments at Different Reproductive Stages

M.Q. Esguerra,[1] C.C. Hemphill,[1] and P.A. Counce[1]

Abstract

High nighttime temperatures (HNT) reduce Arkansas rice yield and quality in many years and in some years, such as 2010 and 2016, the reductions cause serious decreases in farm profitability and market acceptability of Arkansas rice. Our objective was to test critical lines for susceptibility to HNT with a view to implementing a program of selection and evaluation of advanced lines. Two controlled experiments were conducted to test the effects of HNT. There were 6 lines tested: Diamond, Titan, Jupiter, Kaybonnet, Zhe 733 and N22. Titan and Diamond were recently released; Jupiter is a popular Arkansas medium-grain; N22 is an HNT-tolerant medium-grain, ZHE 733 is reported to be HNT-susceptible; and Kaybonnet is reported to be HNT-tolerant. Two separate experiments commencing at 2 reproductive stages were conducted: [(1)–commenced at the R2 stage (flag-leaf collar formation) and (2)–commenced at the R5 stage (elongation of at least one grain on the panicle)]. Treatments were 2 night temperatures: Control [73.4 °F (23 °C)] and HNT [82.4 °(28 °)]. Spikelet fertility (SF) and yield were reduced by HNT for Diamond and ZHE 733 but were not reduced by HNT for Kaybonnet, Jupiter, N22 or Titan when treatment commenced at R2. High nighttime temperatures have no effect on SF and yield when treatment begins at R5 stage. Head rice yield was decreased for Diamond, Jupiter and Kaybonnet in both tests while degree of endosperm chalk increased for Diamond, Jupiter and Titan for both tests. Our results provide a means of confirming other findings and further testing of advanced breeding lines.

Introduction

The Intergovernmental Panel on Climate Change (IPCC) has reported that the global mean surface temperature increased by ~0.9 °F (0.5 °C) in the 20th century and will possibly increase further by 2.0 to 10 °F by 2100 (IPCC, 2007). This increase in temperature was found to be asymmetric with night temperatures increasing faster than the day temperatures (Jin and Dickinson, 2002). In Arkansas, the National Oceanic Atmospheric Administration (NOAA) reported a slight warming since the early 20th century and that the number of nights with temperatures exceeding 75 °F (23.3 °C) has been above average since 1995 (Runkle et al., 2017). They likewise noted that the highest number of warm nights was primarily observed during the five-year period 2010–2014. Recently, due to the asymmetric increase in global temperature, more attention has been paid to rice yield and quality as affected by heat stress during the night. Laborte et al. (2012) have indicated the critical night heat stress temperature as that above 77 °F (25 °C) for a period of 15 days (panicle initiation to maturity). Peng et al. 2004 reported a 10% yield penalty for every 1.8 °F (1 °C) increase in the minimum night temperatures. In 2010, high nighttime temperature (HNT) resulted in increased incidences of chalk and decreased head rice yield (HRY) in Arkansas (Lanning et al., 2011). Developing HNT tolerant cultivars is one of the most effective countermeasures to maintain high yield and quality of rice under anticipated night heat stress. Therefore, several controlled environment experiments in field (Zhang et al., 2013 and Shi et al., 2016) and in growth chambers/greenhouses (Cooper et al., 2008; Mohammed and Tarpley 2009; and Kumar et al., 2017) were conducted to understand the physiological and molecular mechanisms of HNT tolerance/susceptibility. However, many of these studies used either small samples and/or utilized older cultivated varieties. Furthermore, the temperature, duration, and initiation of HNT treatments were often highly variable making comparisons between experiments relatively difficult, hence the need for this study. The objectives of this study were to: (a) evaluate the performance of recently released, and popular varieties i.e., Diamond (a new long-grain), Titan (a new medium-grain), and Jupiter (popular medium-grain) under HNT; (b) validate the HNT tolerance/susceptibility of reported varieties [N22 (medium-grain tolerant), Kaybonnet (long-grain tolerant) and Zhe 733 (long-grain-susceptible)]; and (c) identify the most sensitive reproductive stages [R2(flag-leaf collar formation) to maturity or R5 stage (elongation of at least one grain on the panicle) to maturity] for HNT. Specifically, the authors focused on investigating HNT effects on spikelet fertility (SF), grain yield, HRY and degree of endosperm chalk (DEC).

Procedures

Two independent experiments were conducted: Exp. 1–commenced at the R2 stage and Exp.2–commenced at the R5 stage. Using large growth chambers, 2 night temperatures were compared: Control [73.4 °F (23 °C)] and HNT [82.4 °F (28 °C)], that lasted from 20:00 to 6:00. Day time chamber settings were: temperature from 86.0–91.4 °F (30–33 °C), relative humidity

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[1] Postdoctoral Research Fellow, Program Associate, and Professor, respectively, University of Arkansas Systems Division of Agriculture Rice Research and Extension Center, Stuttgart, Arkansas.

(RH) 70–75 %, irradiance 390 to 1200 µmoles m^{-2} s^{-1} and $C0_2$ at 550 ppm (see Table 1 for details). Varieties screened were: N22 (tolerant check), ZHE 733 (susceptible check), Kaybonnet (tolerant check), Titan , Diamond and Jupiter . Seedlings were started in the greenhouse and grown in 4 × 4 × 10 in. (length by width by depth) rectangular pots containing a 3:2:1 ratio of silt loam topsoil, potting mix (SunGro MM360), and sand. Two seeds per variety were sown in each pot and thinned to 1 seedling 2 weeks after sowing (WAS). Fertilization was administered per pot with the following volume, type and schedule: 50 mL of Peter's solution (20-20-20) (460 g diluted in 5 gal water) at 3 WAS; 50 mL of Urea (46-0-0) (2 mg N mL^{-1}) at 5 WAS; and 50 mL of Urea (46-0-0) (1 mg N mL^{-1}) at the R2 stage. A total of 35 pots per rectangular tub (36 × 24 × 8 in) served as the experimental unit. The RH inside the greenhouse was 60% to 70 % while day and night temperatures were 86.0–89.6 °F (30-32 °C) and 73.4–78.8 °F (23–26 °C), respectively. Natural sunlight served as the major light source in the greenhouse supplemented with metal halide lighting to provide a 13-hour day length. When moved inside the growth chambers, the experiments were laid out in a completely randomized block design with three blocks.

From each plot, the percentage of filled grains (SF) relative to total number of grains from 10 randomly sampled panicles was determined. Yield refers to the threshed grain weights per tub dried to a moisture content of 12.5% using a chamber set at 50% RH and 75.2 °F (24 °C) temperature. For HRY, 110 g rough rice were de-hulled twice using a Mini-testing Husker (Satake, Hiroshima, Japan), milled using McGill No. 2 (RAPSCO, Brookshire, Texas) for 1 min, and divided to whole and broken grains using a Zaccaria cylinder grader (CRZ, Anna, Texas; cylinder groove: 5.5 mm for long-grain and 4.5 mm for medium-grain). The proportion of whole-grain weight over the original rough rice sample weight adjusted to 0.5 surface lipid content (SLC), referred to the HRY. The SLC was determined by scanning 50 g of head rice using near-infrared reflectance (NIR, DA7200, Perten Instruments, Hägersten, Sweden). For DEC, two subsamples of 20-g head rice were scanned using a SeedCount Image Analyser (SeedCount SC5000TR, Next instrument Pty Ltd., Condell Park, NSW, Australia) where DEC referred to the percentage chalk area of the scanned head rice. The SAS v. 9.4 (SAS Institute, Inc., Cary N.C.) was used for data analysis.

Results and Discussion

Overall, the HNT effects on SF (Fig. 1) were only evident when treatment began at the R2 stage as compared to the R5 stage. The SFs were comparable within each variety between the temperature treatments at R5 stage. Except for Titan, most varieties showed a declining trend on SF when subjected to HNT at the R2 stage. However, treatment effects were only significant on Diamond and ZHE 733. Also at R2, Diamond showed the highest decrease in SF (29%) followed by ZHE 733 (23%). Jupiter had stable SF as manifested in its comparable SFs between treatments at R2 and R5 stages. Variety N22 maintained a high SF (82% to 92%) under HNT for both the R2 and R5 stages, confirming its HNT tolerance. On the contrary, ZHE 733 with its significant SF variation, proved to be a good susceptible check for conducting HNT experiments particularly when treatments are conducted during the early reproductive stage. The non-significant effect of HNT to Titan's SF suggests that current medium-grain varieties may be less vulnerable to HNT while the high decline in SF of Diamond highlighted the need to develop HNT-tolerant long-grain rice. Grain yield showed similar results with that of SF (Fig. 2). The negative effects of HNT were only observed for treatments commenced at the R2 stage. Grain yield for both R2 and R5 stages generally decreased under HNT but was only statistically different for ZHE 733 and Diamond at the R2 stage (Fig. 2). Varieties ZHE 733 and Diamond showed an approximately 51% yield decline under HNT relative to control at R2 while Titan had the least with only 3%. The trend similarity between SF and grain yield suggests that SF may be used to measure HNT yield response indirectly.

For both R2 and R5 stages, HRY across varieties tends to decrease under HNT treatment with a more pronounced decrease when HNT commences at R5 stage (Fig. 3). Titan, N22 and ZHE 733 showed comparable HRY at the R2 stage while only ZHE 733 showed statistically similar HRY at the R5 stage. Although ZHE 733 showed stable HRY under HNT, it was noted that its HRY was the lowest HRY across all varieties even under control treatments, making it an undesirable donor for improved HRY at HNT conditions. In general, these results suggest that HNT may have more serious effects on HRY when it commences at the grain filling stage. It also highlighted the need to search for varieties that have acceptable HRYs for both normal and HNT conditions. Results for DEC showed that whenever significant differences between treatments were observed, DEC was always highest at HNT for both R2 and R5 stages (Fig 4). At the R2 stage, N22, ZHE 733 and Kaybonnet showed comparable DECs between treatments while Jupiter and N22 had statistically similar DECs at the R5 stage. The consistent increase in the DECs of Titan and Diamond suggests that both newly released varieties will have more chalk under HNT conditions. The N22 DEC values were maintained across treatments however, its DEC values were still relatively high even in control environments. At early onset of HNT, Kaybonnet seemed to acclimatize to HNT but this tolerance, in terms of maintaining low chalk, diminishes when HNT occurred at the later reproductive stage. These results emphasized the differential effects of HNT on grain quality relative to variety and stage of occurrence. A variety that has an acceptable chalk value under HNT, particularly during the grain filling stage, will be necessary in developing lines with superior grain quality.

Practical Applications

Results of these experiments will inform breeders about the HNT tolerance/susceptibility of their released varieties. This could serve as guide regarding which varieties need to be avoided and which traits have to be improved for HNT tolerance. The methodology used in this study will serve as a useful and important tool for developing lines that have high yield with superior milling and grain quality characteristics under HNT. In the future, advanced lines will be submitted to similar testing to provide breeders with HNT resistance data as varieties are released. In addition, early generation testing will also be done to allow selection for improved resistance to HNT conditions.

Acknowledgments

The authors would like to thank the Arkansas rice growers for their funding and support which is administered through the Arkansas Rice Research and Promotion Board, the University of Arkansas System Division of Agriculture‘s Rice Research and Extension Center, and Rice Processing program for technical support.

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Table 1. Growth chamber settings from the R2/R5[a] stage until physiological maturity.

Treatment	Time (Hour)	Temperature[b] (^{0}F/^{0}C)	Humidity (%)	Irradiance (μmoles m^{-2} s^{-1})	CO$_2$ (ppm)
Both	08:00–12:00	86.0/30	75	790	550
	12:00–15:00	91.4/33	70	1200	550
	15:00–17:00	91.4/33	70	790	550
	17:00–20:00	86.0/30	75	390	550
HNT[c]	20:00–06:00	82.4/28	75	0	550
	06:00–08:00	82.4/28	75	390	550
Control	20:00–06:00	73.4/23	75	0	550
	06:00–08:00	73.4/23	75	390	550

[a] R2–flag-leaf collar formation; R5–elongation of at least one grain on the panicle.

[b] Temperature was set to ramp up/down to the specified temperature in the next time schedule.

[c] HNT–High Nighttime Temperature.

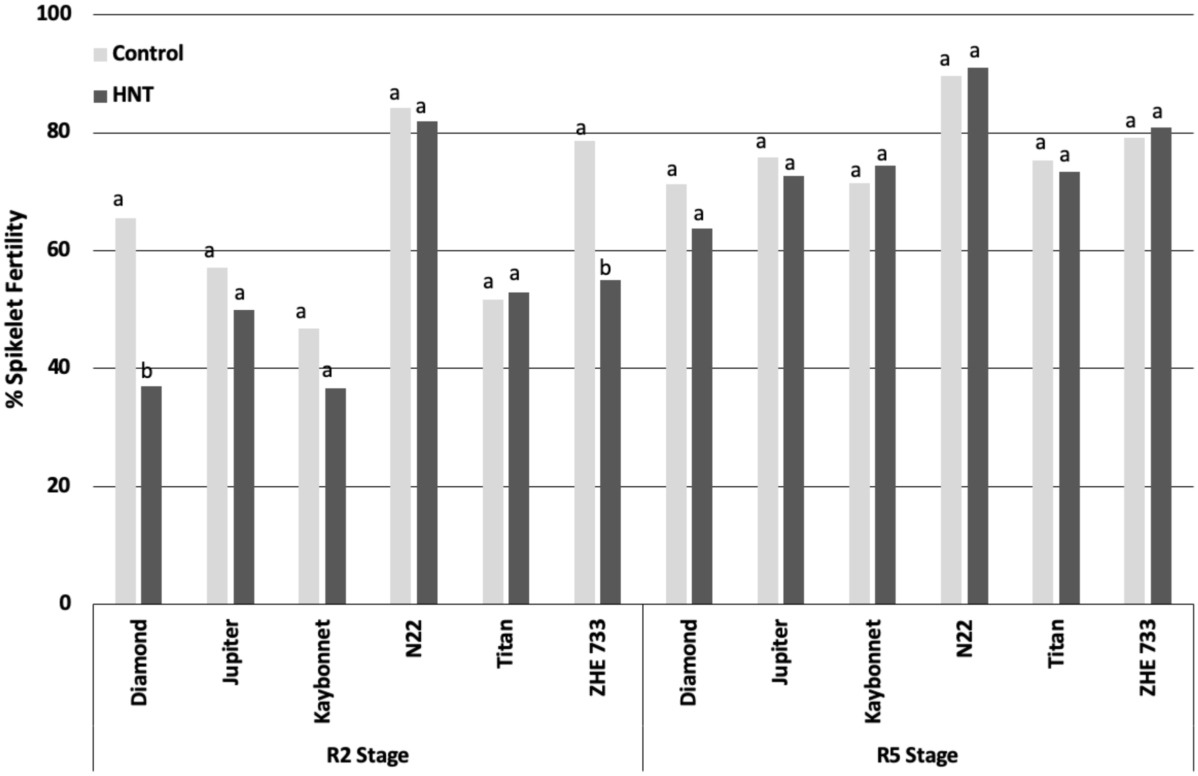

Fig. 1. Spikelet fertility of six selected varieties subjected to two night temperature treatments: Control at 73.4 °F (23 °C) and high nighttime temperature (HNT) at 82.4 °F (28 °C) at either R2 (flag-leaf collar formation) or R5 (elongation of at least one grain on the panicle). Treatment means having the same letter within each variety and stage are not significantly different according to Fisher's protected least significant difference at α = 0.05.

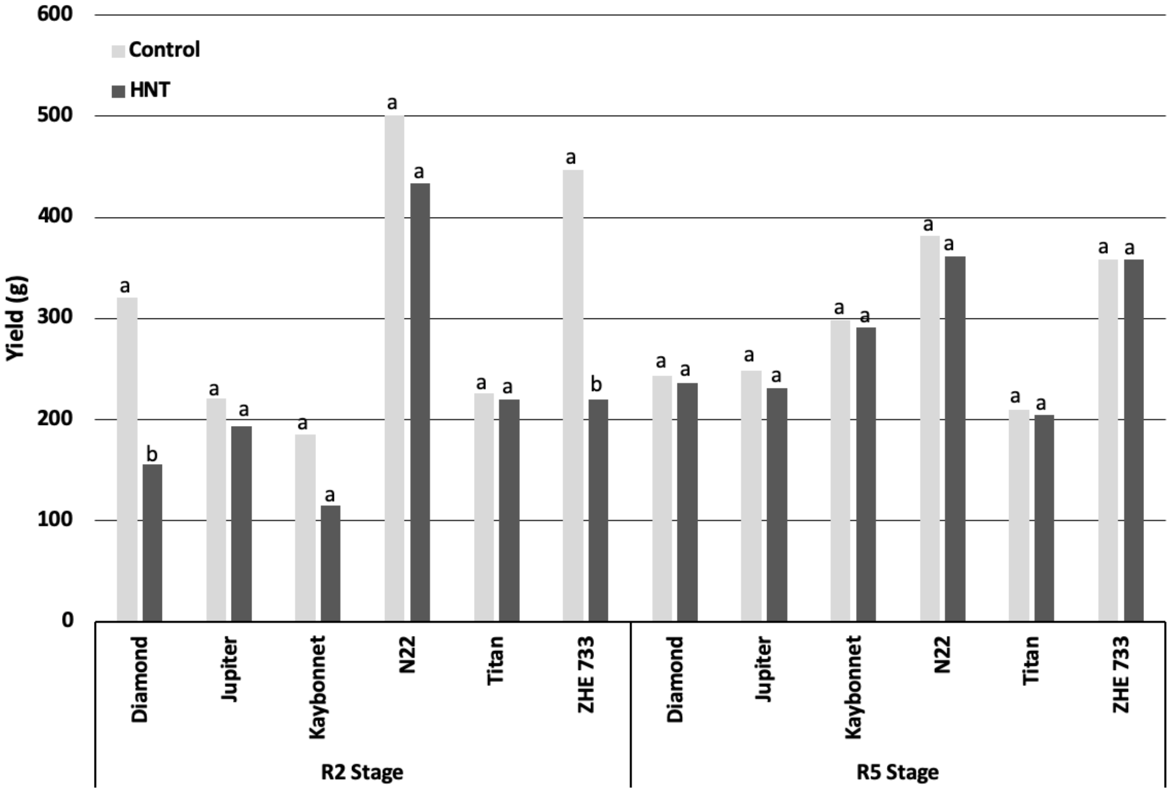

Fig. 2. Yield (35 plants) of six selected varieties subjected to two night temperature treatments: Control at 73.4 °F (23 °C) and high nighttime temperature (HNT) at 82.4 °F (28 °C) at either R2 (flag-leaf collar formation) or R5 (elongation of at least one grain on the panicle). Treatment means having the same letter within each variety and stage are not significantly different according to Fisher's protected least significant difference at α = 0.05.

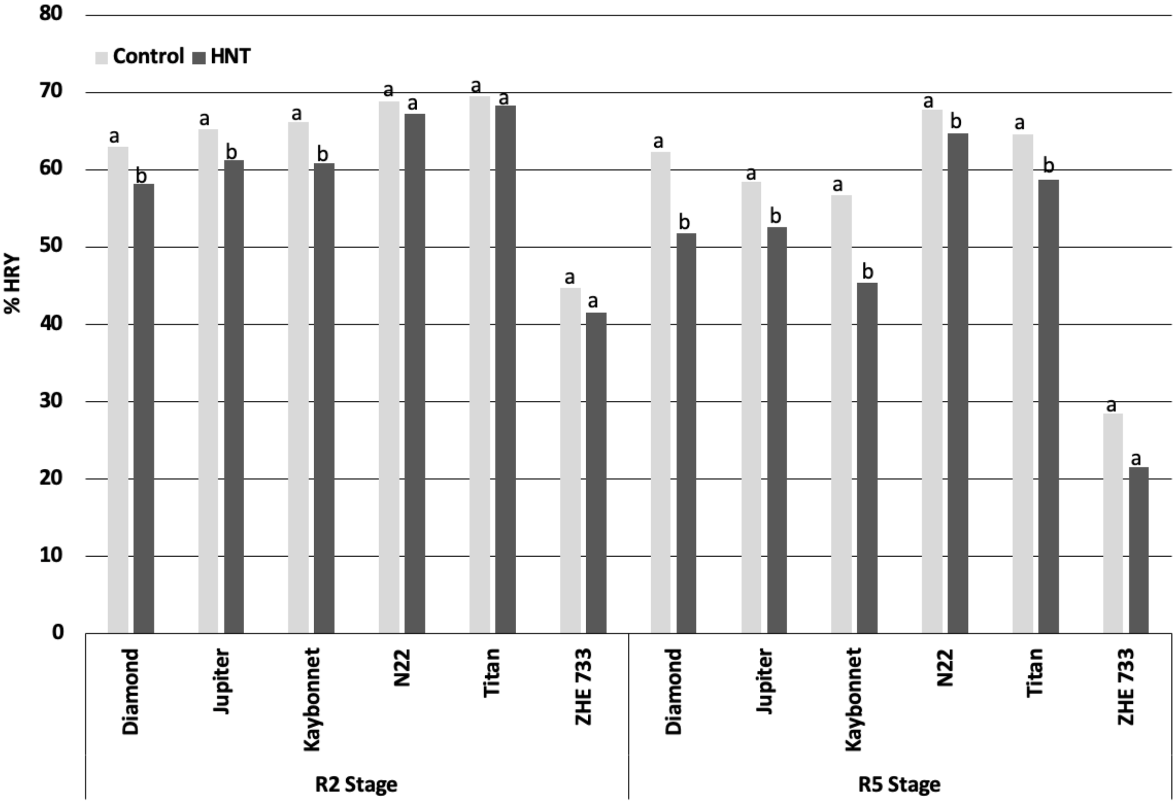

Fig. 3. Head rice yield (HRY) of six selected varieties subjected to two night temperature treatments: Control at 73.4 °F (23 °C) and high nighttime temperature (HNT) at 82.4 °F (28 °C) at either R2 (flag-leaf collar formation) or R5 (elongation of at least one grain on the panicle). Treatment means having the same letter within each variety and stage are not significantly different according to Fisher's protected least significant difference at α = 0.05.

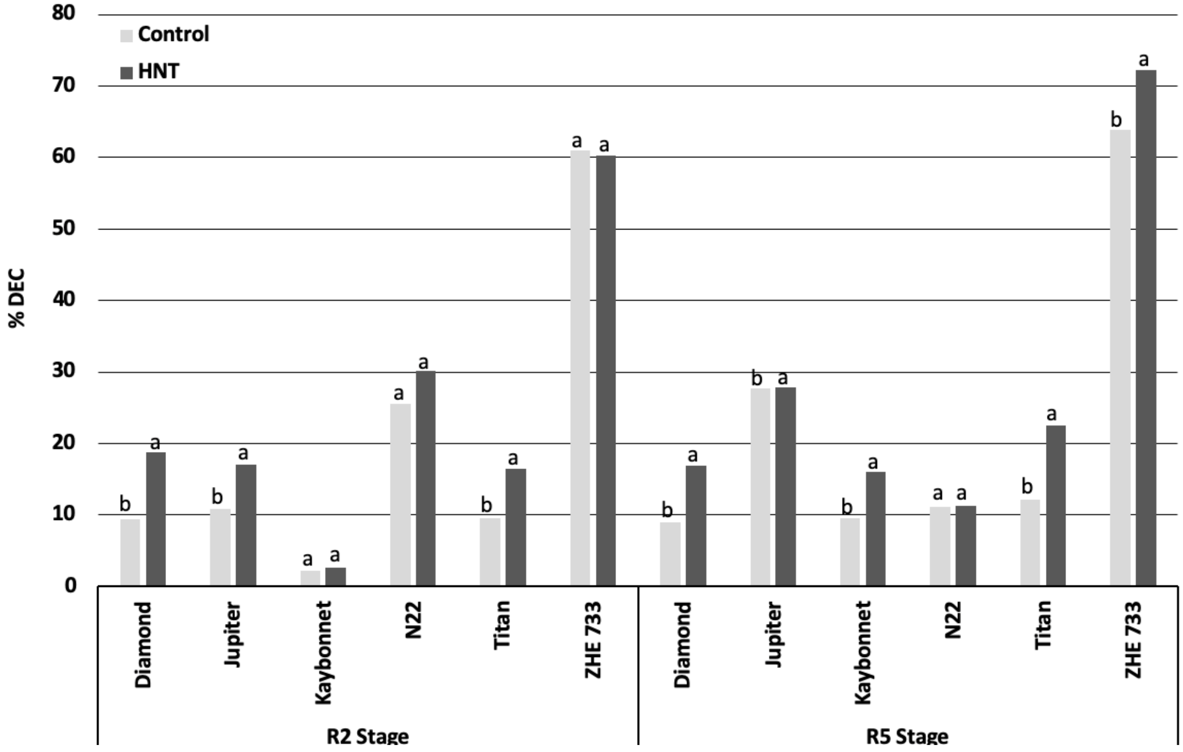

Fig. 4. Degree of endosperm chalk (DEC) six selected varieties subjected to two night temperature treatments: Control at 73.4 °F (23 °) and high nighttime temperature (HNT) at 82.4 °F (28 °) at either R2 (flag-leaf collar formation) or R5 (elongation of at least one grain on the panicle). Treatment means having the same letter within each variety and stage are not significantly different according to Fisher's protected least significant difference at α = 0.05.

Comparing the Effects of Multiple Planting Dates on Rice Grain Yield and Quality

C.C. Hemphill,[1] M.Q. Esguerra,[1] K.A.K. Moldenhauer,[1] X. Sha,[1] E. Shakiba,[1] and P.A. Counce[1]

Abstract

The deleterious effects of high nighttime temperature (HNT) negatively impact the rice industry in Arkansas, the U.S. and the world resulting in lost income for rice producers and processors. Both grain yield and grain quality are affected by HNT, but the specific responses of many cultivars important to Arkansas producers have yet to be documented. Seventy-two rice varieties and advanced lines were planted in a field study on four different dates during two years (2018 and 2019) at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center near Stuttgart, Arkansas. Grain yield, head rice yield, chalk, temperature and sunlight were measured and analyzed. The top ranked lines for grain yield, head rice yield, and chalk were determined in each of the 8 planting date by year combinations. The top ranked long-grain lines for yield included several cultivars adapted to Arkansas including Diamond, Jewel, Templeton and Francis. Varieties in the top ranked for head rice yield included Cybonnet, Chenierie, ARoma 17 and several Arkansas selections. Varieties with the lowest ranked chalk values were Cybonnet, ARoma 17, Templeton, CL172 and two Arkansas advanced lines. The high ranking long-grain lines are suggested as candidates for crosses and future development of new rice cultivars with stable grain yield and quality in both normal and HNT conditions.

Introduction

Changing climate conditions appear to be affecting global temperature. The greatest changes in temperature have been observed at night with cooler nights becoming less frequent and hotter nights becoming more frequent in recent years in Arkansas (Runkle et al., 2017). Average temperatures in Arkansas changed a small amount, but an increase in the number of extreme temperature events has been observed (Pachuari and Reisinger, 2007). The problems caused by high nighttime temperature (HNT) for rice producers has been well documented in past studies. High nighttime temperature has been observed to decrease grain yield (Ziska and Manalo, 1996; Peng et al., 2004), decrease head rice yield (Counce et al., 2005) increase chalk (Lanning et al., 2011) and affect physiological responses related to carbon and nitrogen allocation within the plant (Tashiro and Wardlaw, 1991; Mohammed and Tarpley, 2009).

The effects of HNT depend on the developmental stage of the plant when the stress is experienced (Ambardekar et al., 2011; Lanning et al., 2011; Cooper et al., 2006). For example, cell growth and starch formation in developing seeds may be inhibited if HNT occurs during the grain filling period (R6–R9), or panicle development (R2–R4) may be affected if HNT occurs during the R2 stage. Grain quality has been most vulnerable during the grain filling period (R6–R9) while grain yield is more susceptible during panicle development and seed fertilization (R2–R4). For these reasons developmental stage is an important variable that should be controlled when studying the effects of HNT.

An advantage of highly controlled greenhouse and growth chamber studies is the ability to limit testing to a single variable such as temperature, but the conditions tested in such studies are not always representative of naturally occurring field environments. Consequently, controlled climate experiments are most meaningful when data collected from field studies influence treatment parameters, and results from growth chamber experiments can be interpreted in relation to experimental results in the field.

In this report, our focus is identification of top performing long-grain varieties for the traits of grain yield, head rice yield, and chalk in two years and multiple planting dates within each year. Our goal is to report the most consistent and reliable varieties that exhibit stable grain traits under adverse environmental conditions.

Procedures

A field study reported by Esguerra et al. (2018) was continued in 2019 to provide more robust results and confirmation of previous findings. Seventy-two diverse entries were planted in randomized complete blocks of three replications on four dates in 2019: 16 April, 7 May, 14 May and 28 May. Plots were 3 rows 6 feet long spaced 7.5 inches apart. Nitrogen fertilization was 130 lb/ac.

The dates of two important stages of development (R2 and R4) were recorded for each individual plot. Internal panicle development (R2 stage) was defined as the formation of the collar on the flag leaf, and panicle flowering (heading) was defined as the R4 stage. A plot was recorded as having reached a given stage when 50% of individual plants in the middle row met the definition. Hourly air temperature was recorded using temperature sensors placed above the canopy at the front of each bay. Night lengths were determined using the time of sunrise and sunset for each day, and the 95th percentile of night air temperatures (NT95) was calculated similar to Ambardekar et al. (2011). Field grain mois-

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[1] Program Associate, Post-Doctoral Research Associate, Professor, Professor, Assistant Professor, and Professor respectively, Rice Research and Extension Center, Stuttgart, Arkansas.

tures were measured using a handheld moisture meter (Riceter F, Kett, Villa Park, Calif.), and entries were harvested at a moisture content of 18–22%. Moisture content of harvested samples was equilibrated to 11.5–12.5% using a controlled temperature humidity chamber (CSZRI522WSW/8H, Cincinnati Subzero, Cincinnati, Ohio) maintained at 27 °C and 50% relative humidity. Ensuring optimum moisture content for harvest (Siebenmorgen et al., 2007) and optimum drying conditions (Dillahunty et al., 2000) allowed optimum head rice yields to be achieved for plots and reduced potential confounding from harvest moisture and drying variation.

Brown rice yield was measured as seed weight after 125 g of rough rice were run through a de-huller (Mini-testing Husker, Satake, Hiroshima, Japan). Total white rice yield was measured as seed weight after brown rice was milled (McGill number 2, RAPSCO, Brookshire, Texas; equipped with a 1.5-kg weight on the lever arm situated 15 cm from the milling chamber) for 30 seconds. Head rice yield was measured as grain weight of whole grains after removing broken kernels using a laboratory cylinder grader (CRZ, Zaccaria, Anna, Texas; cylinder groove length was determined by grain type: 5.5 mm for long-grain, 4.5 mm for medium-grain and 3.5 mm for short-grain). Brown rice, total white rice and head rice yield are expressed as percentages of the original 125-g sample.

Seed length, seed width and chalk (degree of endosperm chalkiness) were measured using the image analysis system WinSEEDLE™ (2012, Regent Instruments Inc., Sainte-Foy, Quebec, Canada). Percent chalk was defined as the total area of opaque grain color divided by the total grain area multiplied by 100. Chalk data was collected from the average of two subsamples of 100 whole kernels.

Results and Discussion

The NT95 value is defined as the value at which 95% of night temperatures fall below, and a higher NT95 value indicates a hotter night. A graph of NT95 for each year is shown in Fig. 1. In both 2018 and 2019, NT95 was frequently above a critical threshold of 77 °F with more nights at higher temperatures for the earlier planted rice and progressively fewer nights with higher temperatures for the later planted rice. Many nights had NT95 above 80 °F with more in the 2019 season than in the 2018 season. Consequently, the nights in 2019 were hotter for a longer duration during the entire growth period than in 2018. The average length of the two developmental periods was shorter in the hotter year 2019 due to more rapid Degree-Day 50 (DD50) accumulation. In contrast, day temperature was well within normal ranges and was rarely above 95 °F.

Ranking tables were generated for grain yield, head rice yield, and chalk by comparing long-grain entries between all 8 plantings. If a line was included in the top 20, it was given a one, or a zero if not in the top 20. The sum of those rankings on a scale of 0–8 created a proximate score of stability. Entries were again ranked based on stability scores, and the top lines for each category are reported.

For grain yield, the top 13 long-grain entries were dominated by Arkansas varieties: Diamond, Jewel, Lakast, Roy J, Francis, Templeton, 3 advanced Arkansas breeding lines and 2 indicas, Trenasse, and CL151 (Table 1). Diamond was the only entry to receive a maximum stability score of 8 meaning it performed well in all 4 environments in both years.

The top ranked long-grain lines for head rice yield included Arkansas varieties Cybonnet and ARoma 17 and 2 advanced Arkansas breeding lines (Table 2). Also present are 5 Louisiana cultivars and 2 Texas cultivars.

For chalk, stability scores were generated based on lowest ranked entries (Table 3). The most stable entries included Cybonnet, Templeton, 5 aromatics (including ARoma 17), CL161, CL172 and Presidio. As expected, head rice yield and chalk correlated with each other rather than with grain yield.

The consistent presence of aromatic varieties among top ranked entries for head rice yield and chalk is an interesting trend we have observed. It is not yet known whether the stable quality of aromatic varieties is due to or correlated with the molecular pathways responsible for aromaticity. While the use of such varieties for breeding purposes is limited due to the presence of the aromatic trait, these varieties could be very important in helping to identify genes associated with stable quality. In addition, demand for aromatic varieties such as recently released ARoma 17 has been increasing in recent years and is likely to make Arkansas rice exports more competitive in global markets.

Important control entries were included for reference. These were atypical, non-U.S. standard cultivars including N22, Zhe 733 and Nipponbare. The cultivar N22 has been identified as tolerant to high temperatures in general and HNT specifically in primary literature (Yoshida et al., 1981; Ziska and Manalo, 1996). Also included were 8 standard U.S. medium-grain rice cultivars which frequently had high grain yield and excellent head rice yield. Many adapted medium-grain varieties have significant problems with chalk which leads to processing problems in some cases. The molecular reasons for increased chalk formation in medium-grain varieties is an area of ongoing investigation.

Our main rice crop in Arkansas, however, is U.S. long-grain which is susceptible to grain yield and head rice yield reductions and chalk increases as a result of HNT conditions. The long-grain susceptibility leads to serious income loss in some years as a result of reduced yield and quality. Moreover, the improvements in Arkansas cultivar performance over the last 40 years is primarily the result of exploiting the genetic variability of Arkansas-adapted rice lines rather than incorporating exotic and unadapted lines into our breeding populations. For this reason, we sought to get a good measurement of a set of high yielding, long-grain, Arkansas-adapted lines for yield, head rice yield and chalk. Most of the 55 lines were adapted, U.S. long-grain cultivars and advanced Arkansas breeding lines. Many of our best lines and cultivars, while superior in yield, did not have consistently higher head rice yield or low chalk as noted in the rankings. There were a few notable exceptions such as Cybonnet which had excellent head rice yield and low chalk and Templeton which had both high grain yield and low chalk. Both Cybonnet and Templeton will be used in future crosses. Moreover, such crosses could potentially create improved, adapted, high yielding Arkansas rice cultivars with stable grain yield and quality under HNT conditions.

Practical Applications

Our results have important applications toward five different goals of the current project: (1) HNT susceptibility profiles of important Arkansas varieties grown by producers; (2) establishment of an experimental process for evaluating advanced Arkansas lines to determine HNT susceptibility; (3) increased understanding of critical developmental processes limited by HNT; (4) creation of new crosses between HNT-tolerant lines such as N22 and high yielding, Arkansas-adapted lines such as Diamond; and (5) collaborative work with breeders to develop a pipeline for long-term, continued evaluation of Arkansas lines developed in the future.

Advanced Arkansas long-grain breeding lines are currently being screened in controlled climate conditions using growth chambers. Results from controlled climate tests will be compared to the results from appropriate field tests which will provide more meaningful data for the breeders. Several crosses have been made between N22 and adapted Arkansas cultivars. These crosses have been advanced several generations and future crosses are planned between HNT-tolerant and Arkansas-adapted parental lines indicated in this study.

Acknowledgments

The authors would like to thank the Arkansas producers for the funds administered by the Arkansas Rice Promotion Board for program funding and the University of Arkansas System Division of Agriculture for continued support. Seeds were provided by James Oard, Christian De Guzman, Ed Redona, Rodante Tabien, and Debbie Ahrent-Wisdom.

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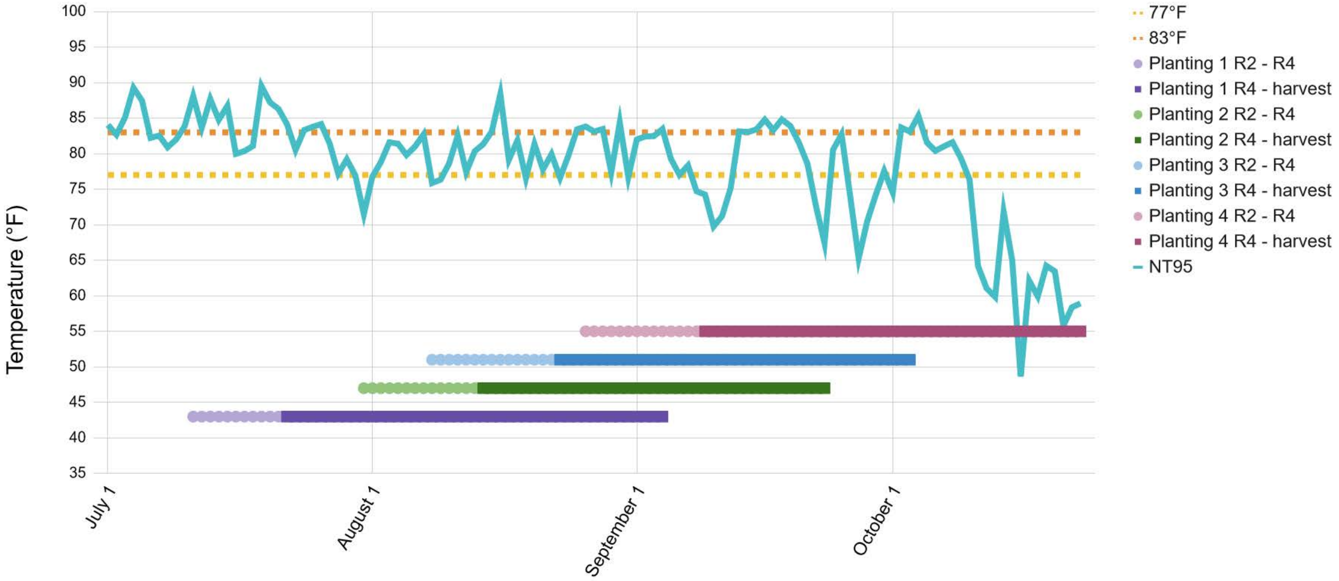
A. 2018 Night Temperatures



B. 2019 Night Temperatures

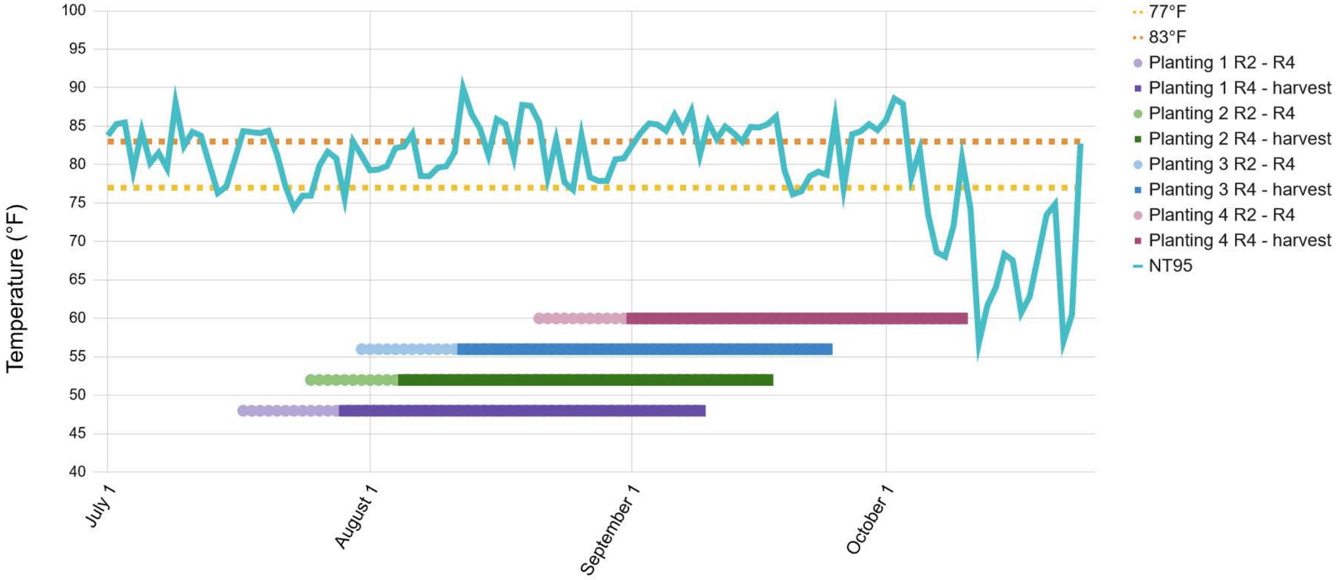


Fig. 1. 95th percentile of night temperature (NT95) for the growing season in 2018 (A) and 2019 (B). Two critical temperature thresholds at 77 °F and 83 °F are shown. Two average growth periods (R2–R4 and R4-harvest) for each planting are indicated.

Table 1. Stability ranking of grain yield for 72 entries across eight plantings in two years.[a]

		2018				2019					
Rank	**Entry**	**P1**	**P2**	**P3**	**P4**	**P1**	**P2**	**P3**	**P4**	**Total**	**Average Grain yield**
											(g)
1	Diamond	1	1	1	1	1	1	1	1	8	446
2	Rondo		1	1	1	1	1	1	1	7	459
3	17AYT006	1	1		1			1	1	5	433
4	367 R				1	1	1	1	1	5	393
5	CL151	1		1		1	1	1		5	422
6	Lakast		1	1	1	1		1		5	422
7	Roy J	1		1	1		1	1		5	402
8	Jewel				1	1	1	1	1	5	402
9	Francis	1	1					1	1	4	424
10	RU1701084	1		1	1			1		4	414
11	Templeton			1	1	1		1		4	421
12	Trenasse		1	1		1			1	4	413
13	Zhe 733			1	1	1	1			4	378

[a] 1 indicates variety was ranked in the top 20 grain yield for that planting by year.

Table 2. Stability ranking of head rice yield for 72 entries across eight plantings in two years.[a]

		2018				2019					
Rank	**Entry**	**P1**	**P2**	**P3**	**P4**	**P1**	**P2**	**P3**	**P4**	**Total**	**Average Head Rice Yield[b]**
											(%)
1	Cybonnet	1	1	1	1	1		1	1	7	61.0
2	ARoma 17		1	1		1	1	1	1	6	61.8
3	Chenierie	1	1	1	1		1	1		6	61.6
4	Antonio	1				1	1	1	1	5	61.9
5	RU1601121	1	1	1	1			1		5	55.7
6	RU1701096		1			1	1	1	1	5	60.4
7	Catahoula	1	1		1			1		4	57.4
8	CL153				1	1	1		1	4	60.8
9	Cocodrie	1		1			1	1		4	60.6
10	Jazzman		1	1				1	1	4	60.7
11	Presidio	1	1		1	1				4	58.6

[a] 1 indicates variety was ranked in the top 20 head rice yield for that planting by year.
[b] Head rice yield = head rice weight divided by original sample weight (125g) multiplied by 100.

Table 3. Stability ranking of chalk for 72 entries across eight plantings in two years.[a]

		2018				2019					
Rank	**Entry**	**P1**	**P2**	**P3**	**P4**	**P1**	**P2**	**P3**	**P4**	**Total**	**Average DEC**[b] **(%)**
1	ARoma 17	1	1	1	1	1	1	1	1	8	0.24
2	Cybonnet	1	1	1	1	1	1	1	1	8	0.45
3	Jazzman 2	1	1	1	1	1	1	1	1	8	0.12
4	Templeton	1	1	1	1	1	1	1	1	8	0.47
5	CL161	1	1	1	1		1	1	1	7	0.67
6	CL172	1		1	1	1	1	1	1	7	0.50
7	Della 2	1	1	1	1	1	1		1	7	0.68
8	Jazzman	1	1	1		1	1	1	1	7	0.25
9	Presidio	1	1		1	1	1	1	1	7	0.48
10	Jasmine 85		1	1		1	1	1	1	6	0.56

[a] 1 indicates variety was ranked in the top 20 head rice yield for that planting by year.

[b] DEC = degree of endosperm chalkiness; opaque area of kernels divided by total area of kernels.

Genome-Wide Association Study for Identification of Novel Genomic Loci Associated with Grain Yield and Quality Traits in *Japonica* Rice under High Nighttime Temperature

A. Kumar,[1] S. Yingling,[1] Y. Dwiningsih,[1] C. Ruiz,[1] J. Thomas,[1] C. Gupta,[1] P. Counce,[2]
T.J. Siebenmorgen,[3] K.A.K. Moldenhauer,[2] and A. Pereira[1]

Abstract

The growing demand for staple food crops like rice will need to be achieved predominantly through agricultural intensification, more efficient use of inputs, and advanced molecular genetics approaches. To meet this demand, it is essential that the genetic diversity within rice subspecies be fully utilized. The *japonica* subpopulation is considered an underappreciated genetic resource within that diversity. It has been shown that *japonica* rice has been well adapted to the Arkansas region and can be a potential gene pool for improving Arkansas traditional rice cultivars. For improvement of the Arkansas rice cultivars, natural genetic variation for grain yield and quality traits need to be quantified at the molecular level. A subpopulation of 81 *japonica* rice genotypes of the USDA Rice Mini Core-Collection (URMC) was phenotyped for grain yield and quality traits under high nighttime temperature conditions in greenhouses, and genotyped by whole genome sequencing, thereby obtaining good quality Single Nucleotide Polymorphism (SNP) molecular markers for genome wide association studies (GWAS). The GWAS was performed using the Circulating Probability Unification (FarmCPU) method with the multiple loci mixed linear model (MLMM), and identified 28 significantly associated SNPs with 100-grain weight (grain yield component), and 42 significantly associated SNPs with percent chalkiness (quality trait) in the subpopulation of 81 *japonica* rice genotypes of the URMC. These novel genomic loci/or SNPs have a potential use in SNP based QTL mapping, identification of candidate genes for grain yield components and quality traits, and the selection of favorable alleles for breeding Arkansas rice cultivars.

Introduction

Rice (*Oryza sativa* L.), one of the world's most important cereal crops, supplies 35–60% of dietary calorie intake for an estimated three billion people (Fageria, 2007; GRISP, 2013). With the improvement of human living standards and the increase in diverse demands, rice grain yield and quality have become one of the foremost goals for rice breeders, producers, and consumers, worldwide. The development of new management and advanced molecular genetics techniques to increase rice grain yield and quality, and the breeding of rice varieties that can yield more under adverse climatic conditions, including more sustainable use of agricultural inputs, are the key targets to meet these demands.

The global mean surface air temperature has increased by 0.85 °C over the period from 1880 to 2012 and is predicted to increase further by 1.0–3.7 °C by the end of 21st century, which will potentially increase the frequency and magnitude of heat stress events (IPCC, 2013).

Under such scenarios, climate change has increased nighttime temperature more than daytime temperature in rice-growing areas worldwide. High nighttime temperature (HNT) has been attributed to the decline in grain yield and quality of rice year by year (Peng et al., 2004). High nighttime temperature at the reproductive stage is one of the important factors, which causes poor grain filling leading to low grain yield and poor grain quality in rice under field conditions, and can be simulated under controlled conditions in the greenhouse (Counce et al., 2005; Kumar, et al., 2017). Rice plants can be affected by increased temperature in several ways at different growth stages: a) vegetative- at panicle initiation; b) reproductive- from panicle initiation to grain filling; and c) ripening- from grain filling to grain maturation (Welch et al., 2010; Kumar et al., 2017).

Within rice subspecies viz., *indica* and *japonica*, there is wide natural genetic variation in grain yield and quality traits (Kumar et al., 2018, 2019). In the United States, the *japonica* rice subspecies is widely cultivated, and is represented by a high proportion of HNT-tolerant genotypes (Kumar et al., 2018). Therefore, quantifying the natural genetic variation using advanced molecular genetics approaches, in HNT tolerance for grain yield and quality traits in *japonica* rice, could be a useful approach; where the identification of favorable alleles for 100-grain weight (100-SW) and/or percent chalkiness (%chalk) of grains are the easiest quantifiable phenotypes. Several studies have been carried out to quantify the natural genetic variation in heat tolerance of the *indica* and *japonica* rice subspecies together (Zhang et al., 2013). However, no studies have yet reported quantifying the natural genetic variation within the *japonica* rice sub-population in response to HNT, as *japonica* rice is potentially an adapted gene

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[1] Post-Doctoral Associate, Program Technician, Graduate Student, Graduate student, Post-Doctoral Associate, Post-Doctoral Associate, and Professor, respectively, Department of Crop, Soil and Environmental Science, Fayetteville.

[2] Professor, and Professor, respectively, Rice Research and Extension Center, Stuttgart.

[3] Distinguished Professor, Department of Food Science, Fayetteville.

pool to enhance rice grain yield and improve the grain quality of U.S. rice cultivars. To quantify the genetic variation in *japonica* rice for 'all the major loci' involved in these traits, it is necessary to make a genome-wide scan, through a genome wide association study (GWAS), for different favorable/unfavorable loci needed for the trait, and use this information for selection and breeding.

Conventionally, the variation has been genetically characterized using bi-allelic mapping populations in several studies. However, with the advancements in whole genome sequencing, the utilization of GWAS have now become common in rice (Huang et al., 2010; Kadam et al., 2017). The most common approach to GWAS is to utilize a diverse population, that maximizes the diversity of the alleles, and to identify a larger number of potential quantitative trait loci/SNPs (Zhao et al., 2011) associated to the target traits.

To quantify the genetic variation in *japonica* rice using GWAS, we initiated a HNT screen of 81 diverse *japonica* rice genotypes (heading at approximately the same time) of the USDA Rice Mini-Core Collection (URMC) as described (Agrama et al., 2009). The objective of the present study was to identify the novel genomic loci/or SNPs associated with grain yield and quality traits under HNT conditions in *japonica* rice genotypes using the GWAS approach.

The identification of novel genomic loci/SNPs, associated with grain yield and quality traits in the *japonica* subpopulation using GWAS mapping, will aid and strengthen the rice breeding program for developing high yielding and good quality rice cultivars for Arkansas rice-growing areas. These loci/SNPs can be used in marker-assisted breeding by rice breeders involved in the Arkansas Rice Research and Extension Center (RREC) molecular breeding program.

Procedures

Plant Materials and HNT Screening Conditions

A subpopulation of 81 diverse *japonica* rice genotypes, selected from the URMC obtained from the Genetic Stocks Oryza Collection (GSOR), of the USDA-ARS Dale Bumpers National Rice Research Center, Stuttgart, Arkansas, was screened under temperature stress treatments in the greenhouses in the Rosen Center at the University of Arkansas System Division of Agriculture in Fayetteville. Rice plants at the R2 (booting stage) and R5 (after anthesis to grain filling) were transferred to HNT of 82.4 °F (28 °C) till grain 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 record the temperature throughout the growth period, which showed continuous HNT during most of the flowering and grain maturity period. At grain maturity (18–20% moisture), panicles were harvested, air-dried, and used for recording the phenotyping data.

HNT Phenotyping and Data Analysis

Plant samples from a subpopulation of 81-*japonica* rice genotypes were harvested at grain maturity and five panicles were taken from each treatment (control and HNT treatments at R5 stage) for weighing 100-grain weight (100-GW). The 100-GW was taken manually from each panicle for each treatment, using a tabletop scale AND GF-3000, after air-drying in the dryer at 70 °C.

Rough rice was de-hulled using a manually operated dehuller (Rice Husker TR120). Chalkiness was measured using an image analysis system WinSeedle™ Pro 2005a (Regent Instruments Inc., Sainte-Foy, Quebec, Canada) and expressed as percent of affected grains in the projected area. Data shown are the average of three replicates with each replicate measured being an average of two 100-grain samples.

For statistical analyses, analysis of variance and full descriptive statistics were performed to analyze the genetic variation among diverse *japonica* rice genotypes for grain yield and quality traits under HNT conditions using SAS 9.4, JMP genomics, and R statistical packages. The mean values of 100-GW and percent chalkiness (% chalk) of each genotype were used for GWAS mapping.

SNP Calling and Genome- Wide Marker-Trait Associations

The genomes of 200 diverse rice genotypes of the URMC were sequenced by Wang et al. (2016) and are publicly available at NCBI (https://www.ncbi.nlm.nih.gov/). All the genomes of 81 *japonica* rice genotypes of the URMC were downloaded and sent to Novogene: Genome Sequencing Company (https://en.novogene.com/) for SNP calling and detection. Novogene detected 3 million (3M) SNPs from the whole genome sequences (WGS) of 81 *japonica* rice genomes. Quality control was performed by visual basic (VB) codes using Excel program and R packages. To filter out the best quality SNPs out of 3M SNPs, we used minor allele frequency (MAF ≥ 2.0%) and missing SNPs ≤ 30% parameters and filtered-out a set of 204,262 good quality SNPs for GWAS.

A GWAS was run using the Fixed and random model Circulating Probability Unification (FarmCPU) tool developed by Liu et al. (2016), and the multiple loci linear mixed-model (MLMM) tool with two principal component covariates for finding the significant SNP-trait associations. The GWAS threshold was set at $-\log_{10}(p)$ 4.0 to detect the most significant SNPs associated with grain yield component (100-GW) and grain quality trait (% chalk) under HNT.

Results and Discussion

To identify the novel genomic loci/or SNPs associated with the 'favorable' grain yield component (100-GW) and 'unfavorable' quality trait (% chalk) in 81 diverse *japonica* rice genotypes of the URMC under HNT, GWAS was performed using an advanced tool, termed FarmCPU, with 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. For the GWAS analysis, we used phenotyping data of 100-GW and % chalk traits and a set of 204,262 good quality SNPs to find the most significant associations with 100-GW and % chalk traits. From the results of the GWAS, we identified 28 significantly associated SNPs for 100-GW (Fig. 1A) and 42 significantly associated SNPs for %chalk (Fig. 1B) in the 81 *japonica* rice genomes. In the figures shown (Fig. 1A and B), these SNPs showed the significance level based on the threshold that was set at $-\log_{10}(p)$ 4.0, with all the most significant associated SNPs seen above the thresholds. For 100-GW, 28 significantly associated SNPs exhibited a marker effect that ranged from 0.22% to 1.3%, while 42 significantly associated SNPs for % chalk showed markers with effects that ranged from 7.5% to 20.1%. These novel genomic loci/or SNPs show potential for SNP-based QTL mapping, identification of linked candidate genes for grain yield components and quality traits, and selection of favorable alleles for breeding Arkansas rice cultivars.

Practical Applications

In this report, we quantify the effect of HNT heat tolerance in different genotypes and identify novel genomic loci or linked SNPs to reveal natural genetic variation for grain yield components and quality traits using a global GWAS approach under HNT stress in the *japonica* rice subpopulation of the URMC. In the GWAS, we found significantly associated SNPs with grain yield components (100-GW) and quality traits (% chalk), and these associated SNPs exhibit potential favorable effects on grain yield components and grain quality traits in the analysis. Therefore, these SNPs can be useful for an SNP-based marker-assisted selection for favorable alleles in the U.S. rice cultivars, especially in the *japonica* rice, QTL mapping, and targeting the candidate genes to dissect biological pathways involved in rice productivity.

Acknowledgments

The authors thank the rice producers of Arkansas for their funding administered by the Arkansas Rice Research and Promotion Board and for the continued support from the University of Arkansas System Division of Agriculture.

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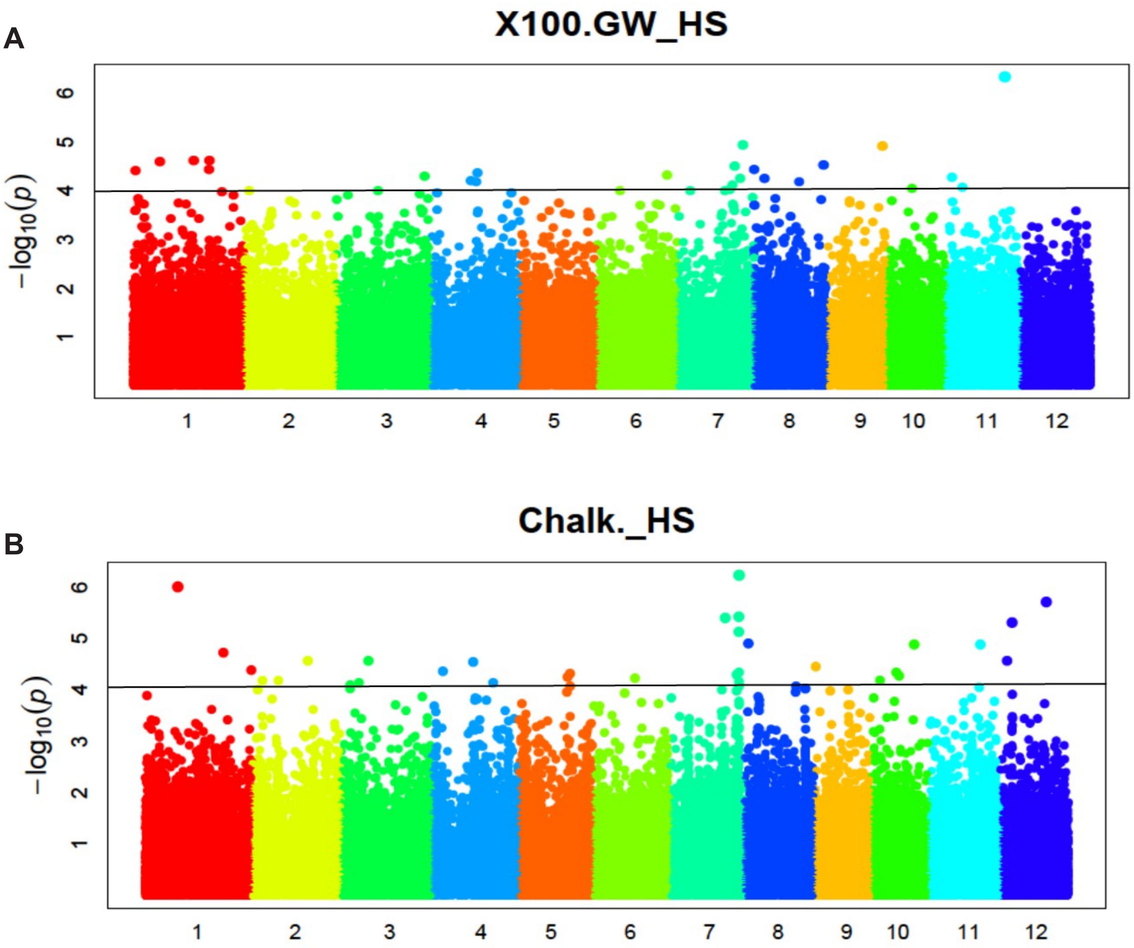

Fig. 1. Genome wide association study for grain yield (100-GW) and quality (% chalk) trait components in a subpopulation of 81 *japonica* rice genotypes of the USDA Rice Mini Core-Collection under high nighttime temperature conditions. The Manhattan plots show significantly associated single nucleotide polymorphisms (SNPs) (>-log$_{10}$*p*) of 4 with 100-GW (A) and percent chalkiness (B). The horizontal black line in each plot represents the threshold that was set at –log$_{10}$(4.0) and each colorful dot in the plots represents single significantly associated SNPs that are above the thresholds in the Manhattan plots. These plots show stronger association of the trait with higher the - log$_{10}$(*p*-value) of the SNPs.

Jewel, High Yielding, Short Season Long-Grain Rice Variety

*K.A.K. Moldenhauer,[1] X. Sha,[1] E. Shakiba,[1] J. Hardke,[2] Y. Wamishe,[3] D. McCarty,[1] C.H. Northcutt,[1]
D.K.A. Wisdom,[1] S. Belmar,[1] C.D. Kelsey,[3] V.A. Boyett,[1] V. Thompson,[1] D.L. Frizzell,[1]
J.M. Bulloch,[1] E. Castaneda-Gonzalez,[1] D.G. North,[1] and B.A. Beaty[1]*

Abstract

Jewel is a new short season, high yielding, long-grain rice cultivar with the *Pi-ta* gene for blast resistance and the Cheniere cook type developed from a complex cross with many parents, some of which are: Katy, Newbonnet, Drew, Lebonnet, Starbonnett, LaGrue, Lemont, Wells, Radiated Bonnet 73, short strawed Starbonnet, Dawn, and Bluebonnet 50. Jewel has been approved for release, by the University of Arkansas System Division of Agriculture's Arkansas Agricultural Experiment Station, to qualified seed growers for the summer of 2020. The major advantages of Jewel are its blast tolerance, yield potential, high whole kernel rice milling yield, long kernel length, low chalk and L-202 cook type. Jewel is a non-semidwarf standard long-grain rice cultivar with lodging resistance approaching that of Roy J. Jewel is rated moderately susceptible to rice blast, sheath blight and false smut, and rated susceptible to bacterial panicle blight.

Introduction

Jewel was developed in the rice improvement program at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC) near Stuttgart, Arkansas, and has been released to qualified seed growers for the 2020 growing season. Jewel has both high rough rice grain yield and milling yield. It is similar in maturity to Diamond, 3 to 4 days earlier than Roy J. It is similar in height to Diamond and LaKast, and has straw strength similar to Diamond, approaching that of Roy J. Jewel has the *Pi-ta* gene for blast resistance like Katy and Drew and the cook type similar to Cheniere. Jewel was developed with the use of rice grower check-off funds distributed by the Arkansas Rice Research and Promotion Board.

Procedures

Jewel rice (*Oryza sativa* L.), is a high yielding, short season, long-grain rice cultivar developed by the Arkansas Agricultural Experiment Station. Jewel originated from the cross STG01P-18-011/RU0001188/7/Lebonnet/CI9902/3/Dawn/CI9695//Starbonnet/4/LaGrue/5/Wells/6/RU9201179 (cross no. 20092592) made at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC), Stuttgart, Arkansas, in 2009. Jewel is a complex line containing many different parents which include: Katy, Newbonnet, Drew, Lebonnet, Starbonnet, LaGrue, Lemont, Radiated Bonnet 73, Short Strawed Starbonnet, Dawn, Bluebonnet 50, Lacrosse, Zenith, Nira, Rexoro, Badkalamkati, Texas Patna, Supreme Blue Rose, L203, Bonnet73, Vegold, Zeawchanica Karatalski, and a sister line of Drew. The experimental designation for early evaluation of Jewel was STG12L-36-206, starting with a bulk of F_6 seed from the 2012 panicle row L-36-206. Jewel was tested in the Arkansas Rice Performance Trials (ARPT) and the Cooperative Uniform Regional Rice Nursery (URRN) during 2017–2019 as entry RU1701087 (RU number indicated Cooperative Uniform Regional Rice Nursery; 17 indicates the year entered, 2017; 01 indicates Stuttgart, Arkansas; and 087 is the entry number).

In 2017 and 2018, the ARPT was conducted at five locations in Arkansas: RREC; Division of Agriculture's Northeast Research and Extension Center, (NEREC), Keiser Arkansas; Pine Tree Research Station, (PTRS), near Colt, Arkansas; a Bowers Farm, Clay County (BFCC) near Corning Arkansas; and the Whitaker Farm, Chicot County (WFCC) near Dumas, Arkansas. In 2019, the trials were grown at RREC, NEREC, PTRS, and BFCC. The tests had four replications per location to reduce soil heterogeneity effects and to decrease the amount of experimental error. Jewel was also grown in the URRN at the RREC; Crowley, Louisiana; Stoneville, Mississippi; Beaumont, Texas from and at Malden Missouri 2017–2019. This test has three replications per location. Data collected from these 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 MP192 (CES, 2018). Agronomic and milling data are presented in Tables 1 and 2. Disease ratings, which are indications of potential damage under conditions favorable for development

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[1] Professor, Professor, Assistant Professor, Program Associate, Program Technician, Program Associate, Program Technician, Program Associate, Program Technician, Program Associate, Program Associate, Program Associate, Program Associate, and Program Associate, respectively, Rice Research and Extension Center, Stuttgart.

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

[3] Extension Plant Pathologist, Associate Professor, and Program Technician, respectively, Department of Plant Pathology, Stuttgart.

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, totally lodged.

Results and Discussion

Rough rice grain yields of Jewel have compared favorably with Lakast and Roy J in the ARPT. In 14 ARPT tests (2017–2019), Jewel, Diamond, LaKast, and Roy J, averaged yields of 187, 205, 191, and 193 bu./ac, respectively (Table 1). Data from the URRN conducted at Arkansas during 2017–2019, showed that Jewel's average grain yield of 229 compared to Diamond, LaKast, RoyJ and Wells at 239, 208, 200, and 214 bu./ac, respectively (Table 2). Milling yields (%whole kernel/% total milled rice) at 12% moisture from the ARPT, 2017–2019, averaged 59/71, 55/70, 56/69, and 57/70, for Jewel, Diamond, LaKast, and Roy J, respectively. Milling yields for the URRN in Arkansas during the same period of time, 2017–2019, averaged 61/70, 60/70, 59/70, 60/71, and 61/72, for Jewel, Diamond, LaKast, Roy J, and Wells, respectively.

Jewel is a short season variety close to the maturity of Diamond and about 3 to 4 days earlier than Roy J. Jewel, like Diamond, has straw strength approaching that of Roy J which is an indicator of lodging resistance. On a relative straw strength scale (0 = very strong straw, 9 = very weak straw), Jewel, Diamond, LaKast Francis, Wells, LaGrue, and Roy J rated 2, 2, 4, 4, 3, 5, and 1, respectively. Jewel, like Diamond and LaKast, has an average canopy height of 37 inches.

Jewel has the genes *Pi-ta* and *Pi-ks* and like Katy and Drew is resistant to common rice blast (*Pyricularia grisea* (Cooke) Sacc.) races IB-1, IB-17, IB-49, IC-17, and IE-1, with summary ratings in greenhouse tests of 0,3,0,0 and 0, respectively, while it rates a 6 to race IE-1K using the standard disease scale of 0 = immune, 9 = maximum disease susceptibility. Jewel is rated MS to sheath blight (*Rhizoctonia solani* Kühn) which compares with Diamond (S), LaKast (MS), Roy J (MS) and Wells (S). Jewel is rated MS for false smut [*Ustilaginoidea virens* (Cooke) Takah] compared to Diamond (VS) and Roy J (S). Jewel is rated S to bacterial panicle blight caused by *Burkholderia* species compared to Roy J (S) and Diamond (MS).

Plants of Jewel have erect culms, dark green erect leaves, and glabrous lemma, palea, and leaf blades. The lemma and palea are straw colored with red to purple apiculi, most of which fade to straw at maturity. Milled kernels of Jewel are 7.07 mm compared to Diamond, LaKast, and Roy J, at 7.17, 7.56, and 7.31 mm, respectively, and individual milled kernel weights of Jewel, Diamond, LaKast, and Roy J, averaged 19.9, 21.4, 22.3, and 21.1 mg/kernel, respectively, from the ARPT 2017–2018 data from the Riceland Foods Inc. Quality Laboratory.

The endosperm of Jewel is nonglutinous, nonaromatic, and covered by a light brown pericarp. Rice quality parameters indicate that Jewel has L202 cook type with high amylose, a weak RVA and intermediate gelatinization temperature for rice cooking quality characteristics as described by Webb et al., 1985. Jewel has an average apparent starch amylose content of 25.6% and an intermediate gelatinization temperature of 70.7 °C as measured by the Riceland Food Inc Quality Laboratory.

Practical Applications

The release of Jewel provides producers with a high yielding, short season, long-grain rice which has the *Pi-ta* gene that confers resistance to the common blast races in Arkansas and the Cheniere or L-202 cook type.

Acknowledgments

I wish to express my appreciation for funding and support for this project from the rice producers of Arkansas through the monies administered by the Arkansas Rice Research and Promotion Board and the University of Arkansas System Division of Agriculture.

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Table 1. Three-year average for yield and three-year average for the agronomic data from the 2017 to 2019 Arkansas Rice Performance Trials for Jewel and other cultivars.

Cultivar	Grain Type[a]	Yield[b] 2017	2018	2019	MEAN	Height[c]	50% Heading	Chalky Kernels[d]	Milling
		-----------------------bu./ac--------------------				(in.)	(days)	(%)	HR/TOT[e]
Jewel	L	192	186	184	187	37	87	1.41	59/71
Diamond	L	206	206	204	205	37	86	1.41	55/69
LaKast	L	188	187	198	191	37	84	1.27	56/69
Roy J[f]	L	196	189	--	193	39	92	1.09	57/70

[a] Grain type L = long-grain.

[b] Yield trials in 2017 and 2018 consisted of five locations, Rice Research and Extension Center (RREC), Stuttgart Arkansas; Pine Tree Research Station (PTRS), Colt, Arkansas; Northeast Research and Extension Center (NEREC), Keiser, Arkansas; Bowers Farm, Clay County (BFCC), Corning, Arkansas; and Whitaker Farm, Chicot County (WFCC); in 2019 the successful trials were grown at RREC, PTRS, NEREC, and BFCC.

[c] Height data is canopy height from 2017–2019.

[d] Data for chalk is from 2017–2018 Riceland Foods Inc. Grain Quality Laboratory data.

[e] Milling figures are head rice/total milled rice 2017–2019.

[f] Roy J data from 2017–2018.

Table 2. Data from the 2017 to 2019 Uniform Regional Rice Nursery (URRN) for Jewel and other check cultivars.

Cultivar	Yield[a] 2017	2018	2019	Mean	Arkansas Yield[b] 2017	2018	2019	Mean	Height[c]	50% Heading[d]	Milling
	---------------bu./acre--------------				---------------bu./acre--------------				(in.)	(days)	HR/TOT[e]
Jewel	201	209	202	204	224	218	245	229	44	84	61/70
Diamond	222	203	198	208	245	219	253	239	44	84	60/70
LaKast	193	190	--	192	201	215	--	208	46	78	59/70
Roy J	209	186	200	198	211	187	202	200	45	89	60/71
Wells	186	170	192	183	209	196	235	213	44	83	61/72

[a] AR = Rice Research and Extension Center, Stuttgart, Arkansas; LA = Rice Research Station Crowley, Louisiana; MO = Malden, Missouri; MS = Stoneville, Mississippi; and TX = Texas A&M, Beaumont Texas.

[b] Arkansas URRN Yields.

[c] Height data is canopy height from AR 2017–2019 only.

[d] Heading data from AR 2017–2019 only.

[e] Milling figures are %Head Rice/%Total Milled Rice data from AR 2017–2019 only.

Investigating Genetic Basis of Resistance to Bacterial Panicle Blight of Rice Under Heat Stress Conditions

L. Ortega,[1] C. Patrick,[1] A. Pereira,[2] and C.M. Rojas[1]

Abstract

Bacterial Panicle Blight (BPB), caused by the bacterium *Burkholderia glumae* has affected rice production in Arkansas. *Burkholderia glumae* causes disease symptoms at different developmental stages but the most devastating effects are observed in reproductive tissues because the bacteria interfere with grain development and consequently, panicles either have low weight grain or no grain. Field data has shown that the disease has been more prevalent in years when the temperatures have been unusually high, especially at night, possibly due to bacterial adaptation to grow at temperatures higher than 104 °F (40 °C). With the continuous rise in global temperatures, it is likely that this disease will be more problematic. Thus, there is an urgent need to develop commercial rice varieties with resistance to BPB even under conditions of heat stress. The development of such commercial rice varieties necessitates the identification of sources of resistance in the rice germplasm. This work presents the screening of a subset of rice accessions for resistance to *B. glumae* under conditions of heat stress. Further work is needed to identify genes responsible for those traits.

Introduction

Burkholderia glumae is the causal agent of Bacterial Panicle Blight (BPB) of rice, a serious disease that has affected rice production in Arkansas and in rice growing areas of the world. *Burkholderia glumae* causes symptoms in seeds and developing seedlings (Iiyama et al., 1995), and in older plants symptoms can develop in leaves and stems (Nandakumar et al., 2009). The most devastating effect occurs at reproductive stages because the bacterium infects reproductive tissues and by doing so, interferes with grain development (Nandakumar et al., 2009; Wamishe et al., 2015). The effects on grain development are reflected in a reduction in grain weight of up to 75% with concomitant yield losses (Fory et al., 2014). Bacterial panicle blight has significantly affected rice production in the U.S. mid-South in years when temperatures have been unusually high, specifically at night (Wamishe et al., 2015; Shew et al., 2019). These observations together with the ability of *B. glumae* to withstand temperatures higher than 104 °F (40 °C) has led to the belief that BPB will become even more devastating with global warming (Ham et al., 2011). We previously conducted a pilot experiment under controlled conditions to test the hypothesis that BPB will be exacerbated with the increase in night temperatures. For that purpose, we inoculated the susceptible varieties Wells and Bengal with *B. glumae* under normal conditions 71.6 °F (22 °C) and under high night temperature 82.4 °F (28 °C), and found that increasing night temperatures to 82.4 °F (28 °C) significantly enhanced disease symptoms (Ortega et al., pers. comm.). Since the trend of increase in global temperatures will likely continue, there is an urgent need to develop high yield commercial rice varieties with resistance to BPB even under conditions of heat stress.

The development of rice varieties requires the identification of sources of resistance in the available germplasm. This work reports the screening of rice accessions from the Genetic Stocks Oryza (GSOR) collection for resistance against *B. glumae* under normal and heat stress conditions. The results revealed a broad range of responses among the accessions to heat stress alone and to a combination of heat stress and *B. glumae*. Further characterization of desirable accessions at the genomic and transcriptomic levels will allow us to more precisely understand the resistance responses to BPB so that information can guide future rice breeding efforts.

Procedures

Screening of rice accessions for resistance against the bacterial pathogen *B. glumae*

We selected 20 rice accessions for the Genetic Stocks Oryza (GSOR) Collection (Table 1). These accessions were planted and grown under normal temperature conditions 86 °F (30 °C) day, 71.6 °F (22 °C night). When panicles began to emerge, plants were inoculated with *B. glumae* or mock-treated with water. Two days after heading, 12 plants were spray-inoculated with *B. glumae* at OD_{600} = 1.0. Four additional plants were treated with water and used as negative controls. Plants inoculated with *B. glumae* were divided into two sets of 6 plants each. One set was kept under normal temperature conditions [86 °F (30 °C) day, 71.6 °F (22 °C) night] and 70% relative humidity, the other set was transferred to an independent greenhouse set to high temperature regime [86 °F (30 °C) day/82.4 °F (28 °C) night] and 70% relative humidity. Similarly, plants treated with water were divided into two sets of 2

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[1] Graduate Student, Research Technician, and Assistant Professor, Department of Entomology and Plant Pathology, Fayetteville.

[2] Professor, Department of Crop, Soil and Environmental Sciences, Fayetteville.

plants each. One set was kept under normal temperature conditions [86 °F (30 °C) day, 71.6 °F (22 °C) night] and 70% relative humidity, the other set was transferred to an independent greenhouse set to high temperature regime [86 °F (30 °C) day/82.4 °F (28 °C) night] and 70% relative humidity. At 3 days post-inoculation (dpi), 4 inoculated panicles were scored by counting the total number of spikelets and the number of spikelets showing discoloration. The severity of the disease was calculated as the percentage of discoloration using the ratio of discolored spikelets over the total number of spikelets.

Results and Discussion

Low levels of discoloration of spikelets were observed in water-treated plants, and maintained at normal temperatures; and the average levels of discoloration ranged from less than 5% up to 30%. However, in spite of the apparent variation among accessions, that variation was not statistically significant (Fig. 1A). Discoloration of the spikelets in water-treated plants maintained at high night temperatures revealed a broad range of responses among the accessions from low levels of discoloration (~5% to 20%) in accessions 310131, 310229, 310301, 310354, 310645, 310747, 310802, 310998, 311551, 311206, 311383, 311385, 311600, 311642, and 311735 to moderate levels of discoloration (25%–40%) in accessions 310111, 311078, 311677, 311795, and 301161 (Fig. 1B). These results suggest that high night temperatures trigger a stress response manifested in discoloration of spikelets. The differences in responses among accessions warrant further investigations.

Inoculation with *B. glumae* dramatically increased the percentages of discolored spikelets (Fig. 2A and 2B) in comparison with water-treated plants. Plants inoculated with *B. glumae* and maintained at normal temperatures showed a broad range of responses from moderate levels (25%–40%) discoloration of spikelets in accessions 310131, 311151, 311385 and 301161, to high levels (40–80%) in accessions 310229, 310354, 310645, 310747, 310802, 310998, 311078, 311206, 311600, 311642, 311677, 311735, 311795, and to very high levels (more than 80%) in accessions 310111, 310301 and 311383 (Fig. 2A). Plants inoculated with *B. glumae* and maintained at high night temperature also showed a broad range of moderate, high and very high levels of discoloration. Among the accessions with moderate levels of discoloration (25%–40%) were: 310802, 311206, 310645 and 301161. Accessions with high levels of discoloration (40%–80%) were: 310131, 310229, 310354, 310747, 310998, 311078, 311385, 311600, 311642, 311677, 311735 and 311795. Accessions with very high levels of discoloration (more than 80%) were: 310111, 310301, 311078 and 311383 (Fig. 2B).

Together, these results show that the effect of the high night temperature on the discoloration of spikelets caused by inoculation with *B. glumae* is accession-specific. Some accessions such as 310111, 310131, 310229, 310301, 311383, 311642 and 311677 showed equivalent percentages of discoloration of spikelets after inoculation with *B. glumae* regardless of the temperature. Other accessions such as: 311078, 311151, 311385, 311795, and 301161, showed higher discoloration of spikelets when inoculated with *B. glumae* and exposed to conditions of heat stress in comparison with plants inoculated with *B. glumae* and maintained in normal conditions. Intriguingly, accessions 310354, 310645, 310747, 310802, 310998, 311206, 311600 and 311735, showed reduced discoloration with the combination *B. glumae* and heat stress in comparison with the combination *B. glumae* and normal temperature conditions (Fig. 2B).

Based on this limited set of accessions, these results showed that high temperature does not necessarily enhance susceptibility to *B. glumae* as initially thought. Rather, the effect of high temperature is accession-specific. Our findings that some accessions showed reduced disease severity at higher temperatures is promising as those accessions represent good sources of resistance to *B. glumae* under heat stress. While these results are important, confirmatory tests are needed to confidently establish that the observed responses are stable and independent of the disease scoring methods. Future analyses comparing genomic and transcriptomics between accessions exhibiting differential responses as well as within accessions exhibiting similar responses will enable us to identify genes responsible for these effects. That information will significantly improve the selection of accessions with the desirable traits to be incorporated into commercial accessions.

Practical Applications

Results from this work and future work may increase the chances of the development of rice accessions with enhanced resistance to BPB and heat stress.

Acknowledgments

This research was supported by the University of Arkansas System Division of Agriculture, the Arkansas Rice Check off Program administered by the Arkansas Rice Research and Promotion Board, and the University of Arkansas Chancellor's Discovery, Creativity, Innovation and Collaboration Fund.

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Table 1. Rice accessions used in this study

Genetic stock (GSOR) accession number	Name	Country of origin
310111	Bombilla	Spain
310131	Secano do Brazil	El Salvador
310219	Red Kosha Cerma	Afghanistan
310301	H57-3-1	Argentina
310354	Padi Pohon Batu	Malaysia
310645	Moroberekan	Guinea
310747	Bhim Dhan	Nepal
310802	Tamanishiki	Japan
310998	WC 4443	Bolivia
311078	Gazan	Afghanistan
311151	TD 70	Thailand
311206	79	Guyana
311383	Darmali	Nepal
311385	Kaukkyi Ani	Myanmar
311600	Jyanak	Bhutan
311642	Tia Bura	Tia Bura
311677	Karabaschak	Bulgaria
311735	Simpor	Brunei
311795	Nipponbare	Japan
301161	Wells	United States

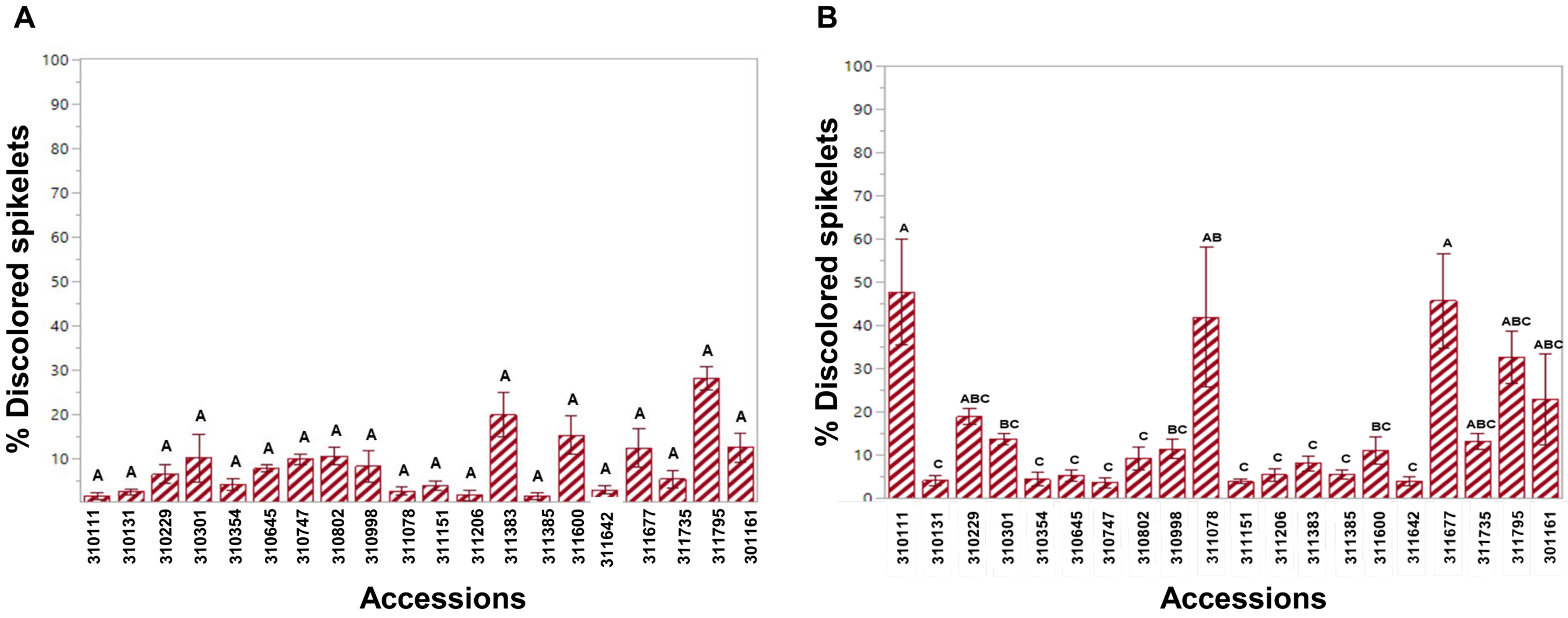

Fig. 1. Responses of rice accessions to heat stress. Rice accessions from the rice genetic stock GSOR USDA mini-core collection were water-treated when panicles began to emerge, and treated plants were kept at normal temperature conditions [day temperature: 86 °F (30 °C), night temperature: 71.6 °F (22 °C)] (A); or at heat stress temperature conditions [day temperature: 86 °F (30 °C), night temperature: 82.4 °F (28 °C)] (B). Discolored panicles were counted after 3 days of treatment. Bars represent means obtained from three replicates. Different letters above the bars indicate statistically significant difference using analysis of variance and Tukey's honestly significant difference test using a *P*-value of 0.05.

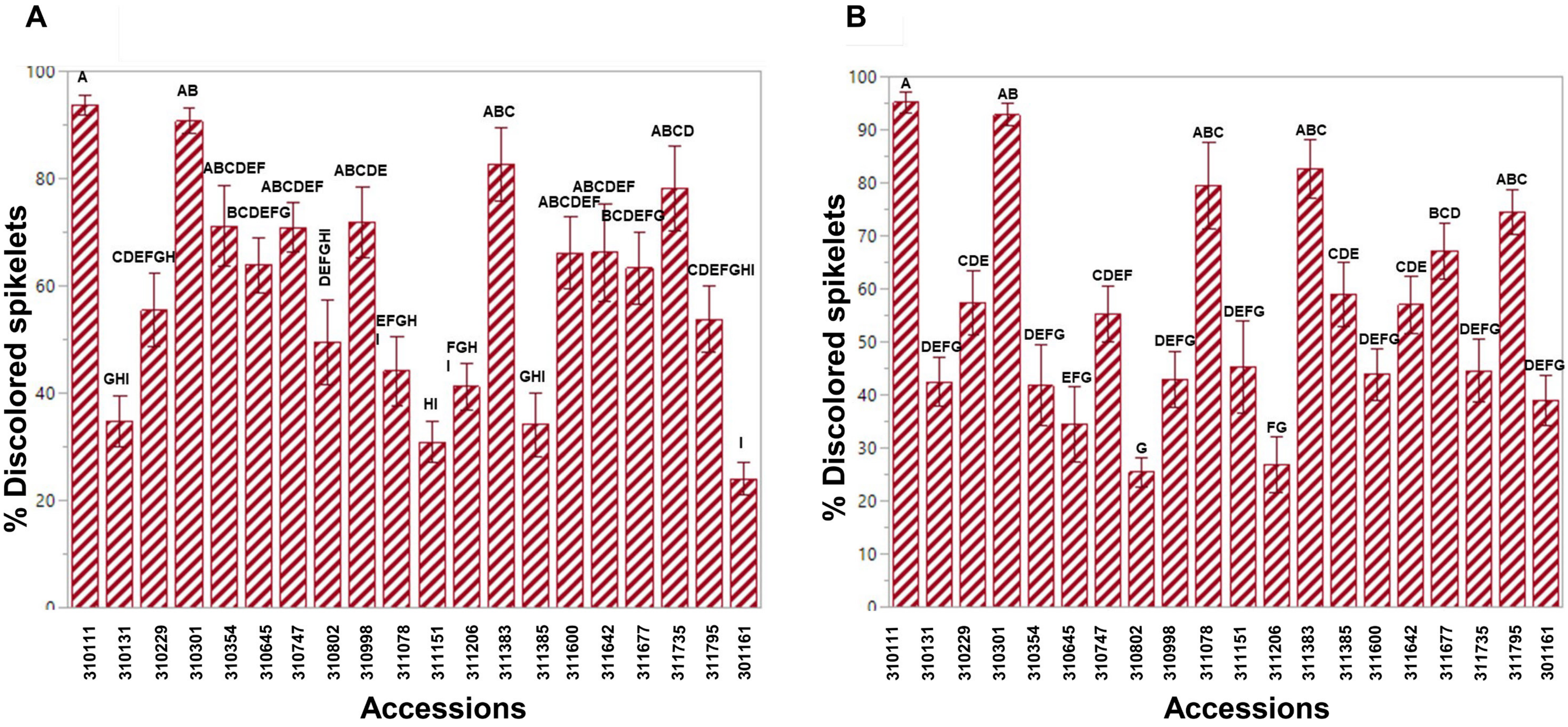

Fig. 2. Responses of rice accessions to *Burkholderia glumae*. Rice accessions from the rice genetic stock GSOR USDA mini-core collection were inoculated with *B. glumae* at an OD_{600} = 1.0 when panicles begun to emerge, and maintained at two temperature regimes: [day temperature: 86 °F (30 °C), night temperature: 71.6 °F (22 °C)] (A); or at heat stress temperatures [day temperature: 86 °F (30 °C), night temperature: 82.4 °F (28 °C)] (B). Discolored panicles were counted after 3 days of treatment. Bars represent means obtained from three replicates. Different letters above the bars indicate statistically significant difference using analysis of variance and Tukey's honestly significant difference test using a *P*-value of 0.05.

Quantitative Trait Loci Mapping of Panicle Architecture and Yield-Related Traits Between Two U.S. Rice Cultivars LaGrue and Lemont

A.D. Rice,[1] E. Shakiba,[2] K.A.K. Moldenhauer,[1] A. Pereira,[2] and A. Shi[3]

Abstract

Grain yield is a quantitative trait that is determined by several yield components, including number of panicles/plant and number of seeds/panicle. There is limited information about the genetics behind yield components in U.S. rice cultivars. The objectives of the study were to 1) conduct a quantitative trait loci (QTL) study for identification of chromosome regions associated with yield traits and 2) look for genes previously mapped in the QTL regions. A bi-parental population was constructed from a cross between LaGrue and Lemont for QTL analysis. Leaf samples from F_2 plants were collected for genetic analysis. About 322 $F_{2:3}$ lines were evaluated in a randomized complete block design for several agronomic traits at two locations (Stuttgart and Pine Tree) with three replications for each line. A total of 15 major QTL were detected including two major QTL for plant height on chromosome 1 and two major QTL for flag leaf length and panicle length on chromosome 8 with eight candidate genes found in these regions. The results from the study would be useful for marker-assisted selection in rice breeding.

Introduction

Rice is one of the most important food crops in the world along with wheat and maize (IRRI, 2019). About half of the world's population relies on rice as part of its diet (Ricepedia, 2019). In the U.S., Arkansas is the top rice-producing state accounting for about 48% of total U.S. rice production (Hardke, 2018). The University of Arkansas System Division of Agriculture's rice breeding program selects for higher grain yield as one of the top priorities in the development of elite rice cultivars. Grain yield is a complex quantitative trait that consists of multiple yield components (Xing and Zhang, 2010). Yield components such as number of tillers/plant, number of panicles/plant, number of seeds/panicle, and seed weight/panicle contribute to overall yield in rice cultivars (Samonte et al., 1998; Devi et al., 2017). Generally, each yield component is controlled by multiple genes that have a small effect on the phenotype and are greatly affected by the environment (Xing and Zhang, 2010). To determine the genetics behind each yield component, a quantitative trait loci (QTL) mapping study was done to look for chromosome regions linked to each yield component.

A QTL mapping study was performed using two U.S. rice cultivars LaGrue and Lemont to look for QTL associated with panicle architecture and yield related traits. There were two objectives for this project: 1) to conduct a QTL mapping study on panicle architecture and other yield-related traits to detect major QTL in the LaGrue × Lemont bi-parental population and 2) to look for candidate genes in the major QTL detected that have been known to control the yield traits examined. Identification of major QTL for these yield traits could be useful for molecular breeding in developing elite rice varieties.

Procedures

Bi-Parental Population Development

We developed a bi-parental population by crossing a U.S. *tropical japonica* long-grain cultivar LaGrue (PI-5688910) with another U.S. *tropical japonica* long-grain cultivar Lemont (PI-475833). Crosses were made in the summer of 2016 and F_1 seed were grown in the spring of 2017 in a greenhouse. The F_1 plants were checked for true/false F_1 using simple sequence repeat (SSR) markers at the molecular genetics lab at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC) near Stuttgart, Arkansas. Seed from each F_1 plant population were harvested and F_2 seed were planted in the greenhouse in the spring of 2018. The F_2 plants in the greenhouse were then tissue sampled for genotypic analysis and seed from each plant was harvested separately to create $F_{2:3}$ families for the phenotypic study.

Phenotypic Evaluation of $F_{2:3}$ Families

In the summer of 2018, 322 $F_{2:3}$ families from the LaGrue × Lemont population were planted in panicle rows at two locations: the RREC and the University of Arkansas System Division of Agriculture's Pine Tree Research Station (PTRS) near Colt, Arkansas. The families were planted in an randomized complete block design with three replications for each family. The lines were planted at PTRS on 10 July and RREC on 11 July. Each replication was planted in its own block. The $F_{2:3}$ families were evaluated in the field for plant height (PH) and 50% heading date (HD). At the end of the growing season, two panicles from each row were sampled to evaluate flag leaf length (FLL), flag leaf

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[1] Graduate Student, Professor, and Assistant Professor, respectively, Rice Research and Extension Center, Stuttgart.

[2] Professor, Department of Crop, Soil, and Environmental Sciences, Fayetteville.

[3] Associate Professor, Department of Horticulture, Fayetteville.

width (FLW), number of primary panicle branches (PBN), number of secondary panicle branches (SBN), and panicle length (PL).

Genotypic Analysis

The LaGrue × Lemont bi-parental population was genotyped using single nucleotide polymorphism (SNP) and SSR markers. Leaf tissue from each F_2 plant was freeze dried and sent to Eurofins Scientific Inc. to be genotyped using an Infinium 7K Rice SNP chip. About 832 SNP markers were found to be polymorphic in the population scattered along the 12 chromosomes of rice.

QTL Mapping and Candidate Gene Analysis

Quantitative trait loci mapping was done using ICI mapping software (Meng et al., 2015). The markers were ordered onto a linkage map using kosambi function. A LOD score of 2.5 was used for QTL detection and QTL with a LOD score of 3.0 or higher were declared as major QTL. The rice genome database Oryzabase was used to search for potential candidate genes previously mapped within major QTL regions detected. The positive parental allele for each major QTL was done using simple t-test in JMP Pro 14.

Results and Discussion

QTL and Candidate Gene Analysis for Yield Traits in $F_{2:3}$ Population

A total of 25 QTL were detected with 15 of the QTL being major (Table 1). Two major QTL for plant height, *qPH1-2* and *qPH1-3*, were co-localized in the same region on chromosome 1 with both having very high LOD scores of 17.4 and 54.4 respectively and together explained 88.0% of phenotypic variation in the population. The QTL for flag leaf length and panicle length, *qPL8-1*, *qPL8-2*, *qFLL8-1*, and *qFLL8-2*, were co-localized in a region on chromosome 8. Candidate gene analysis found a total of 9 genes previously mapped in the major QTL regions including semi-dwarf 1 (*sd-1*) on chromosome 1 and seven genes previously mapped in the flag leaf and panicle length QTL regions called *UBP1-5*, *UBP1-8*, Wide and Thick Grain 1 (*WTG1*), *OsSPL16*, *OsSPL14*, *OsCOL15*, and *OsMADS7* (Table 2). The genes were found to influence plant height, flag leaf length, panicle length and other yield traits such as lodging resistance, number of seeds per panicle, seed weight, and grain yield (Sasaki et al., 2002; Ke et al., 2018; Huang et al., 2017; Wang et al., 2017; Wang et al., 2012; Miura et al., 2010; Wu et al., 2018; Wang et al., 2013).

Practical Applications

Results from this experiment showed major QTL for plant height, flag leaf length, and panicle length. These results could be used in a breeding program for identification of genes within populations via marker-assisted selection.

Acknowledgments

This work was supported in part by funding provided by the rice farmers of Arkansas and administered by the Arkansas Rice Research and Promotion Board. The authors give a special thanks to Dustin North, Daniel Wood, and Thomas Coleman for preparation and fieldwork and to Virginia Boyett for assistance with genotypic analysis.

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Table 1. List of quantitative trait loci (QTL) detected and parental origin of positive allele for major QTL.

QTL	Positive Parental Allele	Location	LeftMarker	RightMarker	BP Position	LOD	PVE(%)	Add	Dom
qFLL2-1		ST	c2p19270352	id2007542	19,270,353-19,294,608	2.70	5.81	-0.71	-0.80
qFLL2-2		ST	SNP-2.28645110.	2369745	28,650,980-31,203,132	2.57	5.74	0.34	1.18
qFLL8-1	LaGrue	ST	SNP-8.26142013.	9030959	26,144,728-27,300,242	3.13	8.03	-1.11	0.51
qFLL8-2	Lemont	PT	SNP-8.26142013.	9030959	26,144,728-27,300,242	3.53	5.97	-1.04	0.09
qFLW2	Lemont	ST	2051794	SNP-2.21778435.	21,329,057-21,784,305	4.04	9.21	-0.05	-0.03
qHD7-2		ST	SNP-7.21232810.	id7004163	21,233,804-23,427,756	2.73	3.45	-1.88	-2.63
qHD1	Lemont	PT	id1025292	1277001	39,799,820-40,032,941	9.44	11.76	-1.43	-0.36
qHD2		PT	2078559	id2010564	22,089,558-24,693,023	2.67	3.27	-0.83	0.07
qHD7-1		PT	7094244	rd7002048	5,185,191-6,855,960	2.54	3.55	-0.31	1.06
qHD8	Lemont	PT	SNP-8.26142013.	9030959	26,144,728-27,300,242	5.51	7.23	-1.10	-0.32
qPL1	LaGrue	ST	SNP-1.37415410.	1212517	37,416,454-37,692,801	4.83	11.15	0.64	0.29
qPL2-1	Lemont	ST	id2004711	SNP-2.11601520.	9,880,575-11,601,525	3.98	9.90	0.46	-0.44
qPL8-1	Lemont	ST	id8006881	8980373	24,803,160-25,658,584	4.42	10.12	-0.55	-0.20
qPL9		ST	rd9002652	9563291	10,798,265-12,154,616	2.82	6.21	-0.26	0.46
qPL2-2	LaGrue	PT	SNP-2.11601520.	c2p17996374	11,601,525-17,996,375	3.10	5.09	0.46	-0.06
qPL7		PT	rd7002219	id7004930	24,113,175-25,945,760	2.96	5.10	-0.48	-0.14
qPL8-2	Lemont	PT	SNP-8.26142013.	9030959	26,144,728-27,300,242	5.14	8.46	-0.57	-0.24
qPBN1	LaGrue	ST	1259171	SNP-1.39395295.	39,342,234-39,396,339	3.36	8.14	0.71	0.41
qPH1-1		ST	222467	SNP-1.7150499.	7,116,232-7,151,500	2.85	4.68	-0.54	-3.09
qPH1-2	LaGrue	ST	SNP-1.38422515.	SNP-1.38536811.	38,423,559-38,537,855	17.38	32.86	6.38	2.27
qPH1-3	LaGrue	PT	1226391	rd1000365	38,258,929-38,361,942	54.39	55.11	9.90	-0.01
qPH8	LaGrue	PT	SNP-8.26090329.	SNP-8.26142013.	26,093,044-26,144,728	3.65	2.38	2.01	0.29
qSBN1-1	LaGrue	ST	SNP-1.38536811.	1237300	38,537,855-38,652,270	7.58	16.27	3.14	0.91
qSBN1-2		PT	1226391	rd1000365	38,258,929-38,361,942	2.83	4.37	1.77	-0.35
qSBN9		PT	rd9002719	SNP-9.17707021.	17,416,860-17,708,023	2.99	4.74	1.87	-0.07

Table 2. List of candidate genes for yield traits.

Gene Id	Gene	Location	Trait	Description
LOC_Os01g66100	sd-1	Chr 1: 38382382 - 38385504	Plant height	semi dwarf 1 gene
LOC_Os01g68120	DCL3A	Chr1: 39605717 - 39595681	Primary Branch Number	Endoribonuclease Dicer homolog 3a
LOC_Os08g41580, Os08g0527600	UBP1-5	Chr 8: 26268141-26263393	Panicle	ubiquitin carboxyl-terminal hydrolase
LOC_Os08g41630, Os08g0528100	UBP1-8	Chr 8: 26299397 - 26287372	Panicle	ubiquitin carboxyl-terminal hydrolase family protein
LOC_Os08g42540	OTUB1, WTG1	Chr 8: 26887363 - 26882955	Panicle,flag leaf	ubiquitin thioesterase otubain-like
LOC_Os08g41940	GW8,OsSPL16	Chr 8: 26501167 - 26506218	Panicle	SBP-box gene family member
LOC_Os08g39890	Wealthy farmers panicle, IPA 1,WFP,OsSPL14	Chr 8: 25278696-25274449	Panicle,flag leaf	SBP-box gene family
LOC_Os08g42440	OsCOL15	Chr8: 26797181 - 26792824	heading date	CCT/B-box zinc finger protein
LOC_Os08g41950	OsMADS7,S45	Chr 8: 26507753 - 26512261	heading date	MADS-box family gene with MIKCc type-box

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

X. Sha,[1] B.A. Beaty,[1] J.M. Bulloch,[1] A. Ablao,[2] S.D. Clark,[2] M. Mann,[3] and M.W. Duren[3]

Abstract

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

Introduction

Complicated 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 single location, 2-replication preliminary yield trials, which include the Clearfield (CL) Stuttgart Initial Trial (CSIT) or Conventional Stuttgart Initial Trial (SIT). Each year, about 1000 new breeding lines are tested in the CSIT or SIT trials. About 10% of the tested breeding lines, which yield 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 Performance Trial (ARPT) that only accommodate about 20 entries from each breeder each year. Obviously, this replicated 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 ARPT trials.

Procedures

A total of 80 entries were tested in 2019 AYT trial, which included 68 experimental lines out of the University of Arkansas System Division of Agriculture's rice breeding program (27 CL long-grain, 15 CL medium-grain, 2 CL Jasmine-type long-grain, 10 conventional long-grain, 1 long-grain hybrid, and 15 conventional medium-grain), and 2 experimental lines out of the Louisiana State University rice breeding program (1 conventional long-grain and 1 Provisia long-grain line), and 10 commercial check varieties. Twenty four of the experimental lines were also concurrently tested in 2019 URRN and/or ARPT trials. The experimental design for all three locations is a randomized complete block with three replications. Plots measuring 5 feet wide (7 rows with an 8-in. row spacing) and 14.25 ft long were drill-seeded at a 75 lb/ac rate. All seeds were treated with AV-1011 (18.3 fl oz/cwt) and CruiserMaxx Rice (7 fl oz/cwt) for blackbird and insects. The soil types at the University of Arkansas System Division of Agriculture's Northeast Research and Extension Center (NEREC), the Pine Tree Research Station (PTRS), and the Rice Research and Extension Center (RREC) are Sharkey clay, Calloway silt loam, and DeWitt silt loam, respectively. Planting dates at the NEREC, PTRS, and RREC were 30 April, 30 April, and 1 April, respectively. A single pre-flood application of 148 lb 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, the 6 rows (including a border row) of each plot were harvested by using a Wintersteiger plot combine (Wintersteiger AG, 4910 Ried, Austria), and the moisture content and plot weight were determined by the automated weighing system Harvest Master that is integrated into the combine. A small sample of seed was collected from the combine for each plot for later milling yield determination. Milling evaluations of the RREC location were conducted by Riceland Foods, Inc. (Stuttgart, Arkansas), while that of the other two locations were conducted in house on a Zaccaria PAZ-100 sample mill (Zaccaria, Limeira, Brazil). Grain yields were calculated as bushel per acre at 12% moisture content.

Data were analyzed using the General Linear Model procedure of SAS software, v. 9.4 (SAS Institute, Cary, N.C.). Analysis of variance for grain yield, milling yields, days to 50% heading, plant height, and seedling vigor was performed for each location, and a combined analysis was conducted across the three locations. The means were separated by Fisher's protected least square difference (LSD) test at the 0.05 probability level.

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[1] Professor, Program Associate, and Program Associate, respectively, Rice Research and Extension Center, Stuttgart.

[2] Program Technician and Resident Director in Charge, respectively, Pine Tree Research Station, near Colt.

[3] Program Technician and Resident Director in Charge, respectively, Northeast Research and Extension Center, Keiser.

Results and Discussion

The average grain yield of all entries across 3 locations is 203 bushel per acre (bu./ac) (Table 1), which is higher than the 195 and 164 bu./ac average in 2018 and 2017, respectively. Among the 3 locations, RREC had the highest yield of 217 bu./ac, followed by 198 bu./ac at PTRS, and 192 bu./ac at NEREC. Overall, medium-grain rice outperformed long-grain rice. The top 5 highest yielding experimental lines are commercial hybrids RT XP753 and RT CLXL745, followed by conventional medium-grain lines 19AYT67 (RU1801211), 19AYT70, and 19AYT63 (Lynx) with the average grain yield of 238, 232, 228, 226, and 221 bu./ac, respectively. The average head rice and total rice of 3 locations are 62% and 71% (Table 2), compared with 67% and 69% in 2018, respectively. The average seedling vigor is 3.3, which is similar to the 3.2 of 2018; the average days to 50% heading is 85 days, and the average plant height is 35 inches.

Eight conventional medium-grain lines, 19AYT67, 19AYT70, 19AYT63 (Lynx), 19AYT62 19AYT76 (RU1901033), 19AYT77 (RU1901125), 19AYT79 (RU1901165) and 19AYT69 (RU1801237), yielded higher than check Jupiter and Titan, which have an average of 215 and 201 bu./ac, respectively. Meanwhile, all 13 CL medium-grain lines have a higher grain yield than CL272, and eleven of them are significant ($P < 0.05$) including 19AYT44 (RU1901169), 19AYT43 (RU1901137), 19AYT05 (CLM04), 19AYT40 (RU1901053), 19AYT45 (RU1801238), and 19AYT42 (RU1901133). Fourteen CL long-grain lines outperformed both CL151 and CLL15, and three of them are significant ($P < 0.05$) including 19AYT53, 19AYT23 (RU1801133), and 19AYT28. The long-grain experimental hybrid 19AYT11 had an average yield of 218 bu./ac, which is about 92% of the top yielder RT XP753. However, 19AYT11 outperformed both RT XP753 and RT CLXL745 at the NEREC location. Most of these top yielding experimental lines will be advanced to or remain in the 2020 ARPT and/or URRN trials, meanwhile 19AYT36 (RU1801169) will be increased/purified at RREC in summer 2020 for potential release.

Practical Applications

The new AYT trial 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 verify the findings from other yield trials, and to identify the outstanding breeding lines, which otherwise were excluded from URRN or ARPT trials due to insufficient space.

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. The authors would like to thank Dean Oliver of Research & Technical Center, Riceland Foods, Inc. for the rice milling and grain quality evaluation. Technical support from Emily Carr and Richard Weaver was greatly appreciated.

Table 1. Grain yield of 80 long- and medium-grain breeding lines and commercial checks in the advanced elite line yield trial (AYT) conducted at University of Arkansas System Division of Agriculture's Northeast Research and Extension Center (NEREC) at Keiser, Arkansas, Pine Tree Research Station (PTRS) near Colt, Arkansas, and Rice Research and Extension Center (RREC) near Stuttgart, Arkansas, 2019.

			Grain Yield (bu.ac)			
Entry	**Pedigree**	**GT†**	**NEREC**	**PTRS**	**RREC**	**Mean**
19AYT01	CL151	CL	193	194	196	194
19AYT02	CL153	CL	160	175	206	181
19AYT03	CLL15	CL	187	201	194	194
19AYT04	CL272	CL	179	182	201	188
19AYT05	CLM04	CM	202	212	238	217
19AYT06	Diamond	L	185	206	231	207
19AYT07	CLXL745	CL	210	233	253	232
19AYT08	XL753	L	231	235	248	238
19AYT09	Jupiter	M	212	221	212	215
19AYT10	Titan	M	191	199	214	201
19AYT11	124A/MH425-3	L	233	196	224	218
19AYT12	RU1001067/TITN	M	188	198	220	202
19AYT13	RICO/BNGL//RU1202068	CM	199	203	237	213
19AYT14	RU1102034/RU1501024*2	CL	180	208	235	207
19AYT15	PVL108	PVL	163	191	196	183
19AYT16	CHNR/MRMT	L	184	154	203	180
19AYT17	RU1102034/RU1302045	CL	186	201	235	207
19AYT18	CL172/RU1102034	CL	190	206	220	205
19AYT19	RU1102034/CL151	CL	175	164	198	179
19AYT20	TITN/CL261	CM	203	178	220	200
19AYT21	TITN/RU1202068	CM	205	177	209	197
19AYT22	RU1201087/RU1202097	CL	176	185	214	192
19AYT23	CL172/4/9502008-A//AR1188/CCDR/3/…	CL	198	221	235	218
19AYT24	STG10IMI-05-034/RU1201145	CL	170	175	199	182
19AYT25	RU1202051/RU1202088	CL	178	171	205	185
19AYT26	RU1002125/RU1202082	CL	168	188	196	184
19AYT27	MRMT/STG10IMI-05-034	CL	182	192	201	192
19AYT28	RU1302048/CL151	CL	218	225	211	218
19AYT29	RU1302048/CL151	CL	195	213	201	203
19AYT30	07SP308/RU1202168	CM	210	204	211	208
19AYT31	RU0902140/RU1201130	CL	187	169	205	187
19AYT32	07SP291/CL261	CM	196	204	214	205
19AYT33	CTHL/CL172	CL	174	168	215	186
19AYT34	JZMN//A-301/KATY/3/RU1202146	CLJ	160	175	190	175
19AYT35	ROYJ/RU1501024	CL	199	193	220	204
19AYT36	ROYJ/RU1501024	CL	187	178	237	201
19AYT37	RU1102131/CL172	CL	173	173	213	186
19AYT38	RU1102131/14CSIT203	CL	177	198	227	200
19AYT39	RU1002146/RU1202146	CLJ	175	178	178	177
19AYT40	CFFY/RU1202168	CM	209	214	228	217
19AYT41	RU1202155/4/WLLS/CFX-18/3/CFX-18//…	CL	183	171	198	184
19AYT42	TITN/RU1202168	CM	204	212	228	214
19AYT43	CL271/JPTR	CM	202	228	224	218
19AYT44	EARL/9902028//RU1202068	CM	214	210	232	219
19AYT45	EARL/9902028//RU1202068	CM	210	203	235	216
19AYT46	RU1102031/CL172	CL	191	180	226	199
19AYT47	14SIT713/CL172	CL	173	178	198	183

Continued

Table 1. *Continued.*

			Grain Yield (bu./ac)			
Entry	**Pedigree**	**GT**†	**NEREC**	**PTRS**	**RREC**	**Mean**
19AYT48	ROYJ*2/RU1401133	CL	188	221	216	208
19AYT49	DMND/RU1501024	CL	174	178	199	183
19AYT50	TITN/RU1501096	CM	197	202	214	205
19AYT51	ROYJ*2/RU1401133	CL	179	195	192	188
19AYT52	ROYJ/RU1501024	CL	193	201	213	202
19AYT53	RU1102131/14CSIT203	CL	209	223	227	219
19AYT54	EARL/9902028//RU1202168	CM	202	205	226	211
19AYT55	RU1102131/CL172	CL	185	211	245	214
19AYT56	RU0902125/RU1102034	L	185	205	233	208
19AYT57	RU1102034/LKST	L	183	188	229	200
19AYT58	CFFY/NPTN	M	194	177	219	196
19AYT59	RU1202131/FRNS	L	166	155	212	177
19AYT60	RU1202131/TGRT	L	185	178	230	197
19AYT61	BNGL/RU0602171	M	208	179	246	211
19AYT62	RU0401064/TITN	M	209	211	240	220
19AYT63	EARL/9902028//JPTR	M	213	226	224	221
19AYT64	RU1102034/FRNS	L	188	176	213	193
19AYT65	RU0902155/RU0902131//RU1201145	L	187	212	203	201
19AYT66	ROYJ/RU1102125	L	187	202	204	198
19AYT67	9865216DH2/EARL//JPTR	M	216	233	235	228
19AYT68	MRMT/RU1102034	L	177	198	208	194
19AYT69	JPTR/EARL	M	208	203	238	216
19AYT70	JPTR/J062	M	219	229	230	226
19AYT71	ROYJ/RU1102034	L	184	220	194	199
19AYT72	RU1301121/TITN	M	186	202	229	206
19AYT73	NPTN/07PY828	M	203	207	221	210
19AYT74	EARL/JPTR	M	194	215	189	200
19AYT75	RU1102034/DMND	L	179	203	204	196
19AYT76	RICO/BNGL//RU0602162/RU0502031	M	221	199	232	218
19AYT77	JPTR/3/EARL//BNGL/SHORTRICO	M	220	213	219	217
19AYT78	RU1001067/JPTR	M	203	198	218	206
19AYT79	RU1001067/RU0602171	M	204	208	240	217
19AYT80	CFFY/RU1202068	CM	192	207	222	207
c.v.(%)‡			6.8	10.8	7.5	8.5
$LSD_{0.05}$			24	30	23	15

† Grain type, CL = Clearfield long-grain, CM = Clearfield medium-grain, L = conventional long-grain, and M = conventional medium-grain.

‡ Coefficient of variance.

Table 2. Average seedling vigor (SV), days to 50% heading (HD), plant height (HGT), and milling yields (MY, % head rice/% total rice) of 2019 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, Arkansas, the Pine Tree Research Station (PTRS) near Colt, Arkansas, and the Rice Research and Extension Center (RREC) near Stuttgart, Arkansas.

Entry	Pedigree	GT†	SV‡	HD	HGT	%HR/ %TR§
					(in.)	
19AYT01	CL151	CL	3.0	85	35	63/70
19AYT02	CL153	CL	3.8	88	34	62/69
19AYT03	CLL15	CL	3.0	86	33	62/68
19AYT04	CL272	CL	3.0	85	35	58/70
19AYT05	CLM04	CM	3.0	87	37	62/70
19AYT06	Diamond	L	3.0	88	36	57/69
19AYT07	CLXL745	CL	3.2	81	39	61/70
19AYT08	XL753	L	3.3	82	38	61/71
19AYT09	Jupiter	M	3.0	87	34	58/69
19AYT10	Titan	M	3.0	82	34	59/70
19AYT11	124A/MH425-3	L	3.6	81	37	56/69
19AYT12	RU1001067/TITN	M	3.1	83	32	65/70
19AYT13	RICO/BNGL//RU1202068	CM	3.0	86	37	64/71
19AYT14	RU1102034/RU1501024*2	CL	3.0	86	37	60/69
19AYT15	PVL108	PVL	3.0	85	36	64/71
19AYT16	CHNR/MRMT	L	3.0	84	34	63/70
19AYT17	RU1102034/RU1302045	CL	3.0	83	35	60/71
19AYT18	CL172/RU1102034	CL	3.1	88	35	63/70
19AYT19	RU1102034/CL151	CL	3.0	86	35	62/70
19AYT20	TITN/CL261	CM	3.0	86	30	61/70
19AYT21	TITN/RU1202068	CM	3.4	84	34	61/69
19AYT22	RU1201087/RU1202097	CL	3.3	81	34	64/70
19AYT23	CL172/4/9502008-A//AR1188/CCDR/3/…	CL	3.0	84	34	63/70
19AYT24	STG10IMI-05-034/RU1201145	CL	3.3	87	35	64/71
19AYT25	RU1202051/RU1202088	CL	3.4	82	36	60/70
19AYT26	RU1002125/RU1202082	CL	3.2	82	33	66/72
19AYT27	MRMT/STG10IMI-05-034	CL	3.2	83	31	63/72
19AYT28	RU1302048/CL151	CL	3.7	81	33	63/70
19AYT29	RU1302048/CL151	CL	3.6	80	36	62/68
19AYT30	07SP308/RU1202168	CM	3.2	84	34	63/71
19AYT31	RU0902140/RU1201130	CL	3.2	88	37	61/70
19AYT32	07SP291/CL261	CM	3.4	83	34	60/69
19AYT33	CTHL/CL172	CL	3.3	88	33	62/70
19AYT34	JZMN//A-301/KATY/3/RU1202146	CLJ	3.3	84	34	66/71
19AYT35	ROYJ/RU1501024	CL	3.7	84	36	58/69
19AYT36	ROYJ/RU1501024	CL	3.2	88	35	62/70
19AYT37	RU1102131/CL172	CL	3.3	87	35	63/70
19AYT38	RU1102131/14CSIT203	CL	3.3	87	34	63/70
19AYT39	RU1002146/RU1202146	CLJ	3.0	83	34	64/69
19AYT40	CFFY/RU1202168	CM	3.0	88	35	58/72
19AYT41	RU1202155/4/WLLS/CFX-18/3/CFX-18//…	CL	3.2	84	35	61/71
19AYT42	TITN/RU1202168	CM	3.1	85	37	63/70
19AYT43	CL271/JPTR	CM	3.1	88	34	57/71
19AYT44	EARL/9902028//RU1202068	CM	3.3	87	36	56/71
19AYT45	EARL/9902028//RU1202068	CM	3.0	86	35	62/71
19AYT46	RU1102031/CL172	CL	3.2	86	36	65/71

Continued

Table 2. ***Continued.***

Entry	Pedigree	GT[†]	SV[‡]	HD	HGT (in.)	%HR/ %TR[¶]
19AYT47	14SIT713/CL172	CL	3.1	88	34	64/70
19AYT48	ROYJ*2/RU1401133	CL	3.2	88	40	62/71
19AYT49	DMND/RU1501024	CL	3.2	87	42	62/70
19AYT50	TITN/RU1501096	CM	3.1	81	35	59/70
19AYT51	ROYJ*2/RU1401133	CL	3.3	89	40	60/69
19AYT52	ROYJ/RU1501024	CL	3.7	87	36	58/69
19AYT53	RU1102131/14CSIT203	CL	3.2	87	34	64/71
19AYT54	EARL/9902028//RU1202168	CM	3.4	87	34	63/71
19AYT55	RU1102131/CL172	CL	3.6	87	33	63/70
19AYT56	RU0902125/RU1102034	L	3.1	82	32	61/70
19AYT57	RU1102034/LKST	L	3.1	88	32	61/70
19AYT58	CFFY/NPTN	M	3.1	82	34	56/71
19AYT59	RU1202131/FRNS	L	3.6	82	34	62/71
19AYT60	RU1202131/TGRT	L	3.7	89	37	61/71
19AYT61	BNGL/RU0602171	M	3.1	83	35	59/71
19AYT62	RU0401064/TITN	M	3.4	84	34	64/71
19AYT63	EARL/9902028//JPTR	M	3.0	86	35	56/70
19AYT64	RU1102034/FRNS	L	3.3	84	40	61/70
19AYT65	RU0902155/RU0902131//RU1201145	L	3.6	83	34	62/71
19AYT66	ROYJ/RU1102125	L	3.7	82	41	55/70
19AYT67	9865216DH2/EARL//JPTR	M	3.6	82	37	62/70
19AYT68	MRMT/RU1102034	L	3.2	84	36	63/70
19AYT69	JPTR/EARL	M	3.4	86	32	60/70
19AYT70	JPTR/J062	M	3.0	86	35	58/69
19AYT71	ROYJ/RU1102034	L	3.2	85	33	61/71
19AYT72	RU1301121/TITN	M	3.2	81	34	63/71
19AYT73	NPTN/07PY828	M	3.3	86	33	58/70
19AYT74	EARL/JPTR	M	3.0	86	34	61/70
19AYT75	RU1102034/DMND	L	3.4	87	36	59/69
19AYT76	RICO/BNGL//RU0602162/RU0502031	M	3.1	83	32	62/71
19AYT77	JPTR/3/EARL//BNGL/SHORTRICO	M	3.4	86	35	57/69
19AYT78	RU1001067/JPTR	M	3.0	84	34	63/70
19AYT79	RU1001067/RU0602171	M	3.3	85	33	60/69
19AYT80	CFFY/RU1202068	CM	3.7	87	35	61/71
c.v.(%)[¶]			11.6	1.9	3.6	2.8/1.0
LSD$_{0.05}$			0.3	1.5	1.2	1.6/0.6

[†] Grain type, CL = Clearfield long-grain, CM = Clearfield medium-grain, L = conventional long-grain, and M = conventional medium-grain.

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

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

[¶] Coefficient of variance.

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

X. Sha,[1] K.A.K. Moldenhauer,[1] E. Shakiba,[1] J.T. Hardke,[2] Y.A. Wamishe,[3] N. Bateman,[3] B.A. Beaty,[1] J.M. Bulloch,[1] D.K.A. Wisdom,[1] D.L. McCarty,[1] D.G. North,[1] V.A. Boyett,[1] and D.L. Frizzell[1]

Abstract

To reflect the recent changes of the Arkansas rice industry and streamline 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 both conventional and Clearfield medium- and long-grain rice as well as hybrid rice. The newest elite breeding lines/varieties from collaborating programs, as well as lines with diverse genetic origins will be actively collected, evaluated, and incorporated into current crossing blocks for programmed hybridization. To improve the efficiency and effectiveness of the program, maximum mechanized-operation, multiple generations grown in the winter nursery, and new technologies such as molecular marker-assisted selection (MAS) are rigorously 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 2010–2019, an average of 0.18 million acres of medium-grain rice were grown annually, making up about 13% of total state rice acreage (USDA-ERS, 2020). A significant portion of Arkansas rice area was planted to semi-dwarf long-grain varieties, such as CL151, CL153, CL172, and Cheniere. Locally developed varieties for Arkansas offer advantages including better stress tolerance and more stable yields. Improved semi-dwarf long-grain lines 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 expansion of hybrid rice may be constrained by its inconsistent milling yield, poor grain quality, lodging susceptibility, seed shattering, 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 blast resistance and physicochemical characteristics. 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, Arkansas and the winter nursery in 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. Small size sample milling, as well as physicochemical analysis at Riceland 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) and Clearfield SIT (CSIT) at the RREC the Advanced Elite Line Yield Trial (AYT) and Clearfield AYT (CAYT) at the RREC, University of Arkansas System Division of Agriculture's Pine Tree Research Station (PTRS) near Colt, Arkansas, and University of Arkansas System Division of Agriculture's Northeast Research and Extension Center (NEREC) in Keiser, Arkansas. Advanced yield testing includes the Arkansas Rice Performance Trials (ARPT) conducted by Jarrod Hardke, the Arkansas rice agronomy specialist, at six locations in rice-growing regions across the state, and the Uniform Regional Rice Nursery (URRN) conducted in cooperation with public rice breeding programs in California, Louisiana, Mississippi, Missouri, and Texas. Promising advanced lines are provided to cooperating projects for the further evaluation of resistance to sheath blight, blast, and panicle blight, grain and cooking/process-

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[1] Professor, Professor, Assistant Professor, Program Associate, Program Associate, Program Associate, Program Associate, Program Associate, Program Associate, and Program Associate, respectively, Rice Research and Extension Center, Stuttgart.

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

[3] Associate Professor and Assistant Professor, respectively, Department of Entomology and Plant Pathology, Stuttgart.

ing quality, and nitrogen fertilizer requirements. All lines entered in the SIT or CSIT and beyond will be planted as head rows for purification and increase purposes.

Results and Discussion

A great number of breeding populations have been created and rapidly advanced since 2013 when the senior author was hired. The field research in 2019 included 1154 transplanted or drill-seeded F_1 populations, 869 space-planted F_2 populations, and 58,240 panicle rows ranging from F_3 to F_7. Visual selection on approximate 800,000 individual space-planted F_2 plants resulted in a total of 40,000 panicles which will be individually processed and grown as F_3 panicle rows in 2020. From those panicle rows, 4402 were selected for advancement to next generation; 1447 rows appeared to be uniform and superior to others and therefore were bulk-harvested by hand as candidates of 2020 SIT or Clearfield SIT (CSIT) trials. In 2019 CSIT, we evaluated 554 new breeding lines, which included 454 CL long-grain, 91 CL medium-grain, and 9 CL jasmine-type aromatic long-grain lines. Of 620 new conventional breeding lines tested in the SIT trial, 402 were long-grain lines and 218 were medium-grain lines. Marker-assisted selection was conducted on all preliminary yield trial entries and backcrosses by using 11 simple sequence repeat (SSR) and single nucleotide polymorphism (SNP) molecular markers for physicochemical characteristics, blast resistance, and herbicide resistance. An 80-entry Advanced Elite Line Yield Trial was conducted at NEREC and PTRS in addition to RREC, while a new 40-entry CL AYT (CAYT) was tested at RREC and PTRS, which was treated with twice the recommended rate of NewPath herbicide. A number of breeding lines showed yield potential similar to or better than the check varieties (Tables 1–4), and will be advanced to advanced yield trials in 2020. Twenty-four advanced experimental lines were evaluated in the multi-state URRN and/or statewide ARPT trials. Results of those entries and selected check varieties are listed in Table 5. Two Puerto Rico winter nurseries consisting of 9180 7-foot rows were planted, selected, harvested, and/or advanced throughout 2019. A total of 920 new single crosses and backcrosses were made to incorporate desirable traits from multiple sources into adapted Arkansas rice genotypes, which included 303 CL long-grain, 109 CL medium-grain, 302 conventional long-grain, 172 conventional medium-grain, and 34 B (maintainer line—maintains the sterility of the cytoplasmic male sterile line) and R (restorer line crosses to the male sterile line to produce hybrid seed) line crosses. We also made 49 single crosses and 124 backcrosses for newly established Provisia breeding projects, as well as 328 testcrosses and backcrosses for hybrid rice breeding.

Semi-dwarf CL long-grain variety CLL15 and the first ever University of Arkansas System Division of Agriculture developed CL medium-grain variety CLM04 continuously performed well in 2019 trials. Certified/registered seeds have been produced by Horizon Ag (Memphis, Tennessee) and should be readily available to rice growers for 2020 season. The conventional medium-grain line 17AR1121 (RU1701121) has shown excellent yield potential in ARPT and other multi-state and multi-location trials for the last 3 years, and it has been approved by University of Arkansas System Division of Agriculture for official release as Lynx for seed rice production in 2020. Foundation seed production is planned for the premium quality Southern medium-grain line 17AR1127 (RU1701127), which has the potential for the newly opened Chinese market. One hundred and thirty-two breeding lines and three experimental long-grain hybrids that outperformed commercial check varieties in AYT, CAYT, CSIT, and SIT trials were selected and further evaluated in the laboratory as candidates for 2020 advanced yield trials including ARPT and/or URRN.

Practical Applications

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

This research is partially funded by rice grower monies administered by the Arkansas Rice Research and Promotion Board. Support also provided by the University of Arkansas System Division of Agriculture. We thank Emily Carr and Richard Weaver for their technical support.

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Table 1. Performance of selected Clearfield long-grain experimental lines and check varieties in the Clearfield Stuttgart Initial Trial (CSIT) at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center near Stuttgart, Arkansas, 2019.

Variety/Line	Pedigree	Seedling vigor†	Days to 50% heading	Plant height	Yield	Milling yields	
						Head rice	Total rice
				(cm)	(bu./ac)	(%)	(%)
19CSIT416c	DMND/RU1501164	3.5	76	110	237	50.5	69.1
19CSIT522c	DMND/CL172	3.0	79	100	237	56.9	68.7
19CSIT486c	16AYT045/RU1201136	3.5	82	112	236	59.3	70.9
19CSIT352c	CTHL/CL172	4.0	84	102	233	59.4	69.8
19CSIT320c	ROYJ/RU1501024	3.5	79	103	228	50.4	67.8
19CSIT321c	ROYJ/14CSIT203	3.5	81	101	227	57.9	69.3
19CSIT512c	DMND/RU1501185	3.0	81	104	225	55.4	68.7
19CSIT303b	RU1102034/RU1501024*2	3.0	87	104	222	59.8	69.6
19CSIT539c	DMND/RU1701096	3.0	77	103	222	52.1	68.9
19CSIT050a	RU0902028/STG10IMI-05-034	3.0	92	93	221	61.1	70.4
19CSIT114a	RU1202131/RU1401044	3.0	92	103	220	56.9	71.0
19CSIT163a	RU1102131/RU1302045	3.0	95	99	219	55.2	68.8
CL151a	CL151	3.0	93	102	209	64.9	69.0
CL153a	CL153	3.0	95	99	188	63.0	67.0
CLL15b	CLL15	3.0	86	98	203	63.3	70.6

† A subjective 1–7 rating taken at emergence, 1 = perfect stand and 7 = no stand.
a = planted on April 1; b = planted on April 30, and c = planted on May 13.

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, Arkansas, 2019.

Variety/Line	Pedigree	Seedling vigor†	Days to 50% heading	Plant height	Yield	Milling yields	
						Head rice	Total rice
				(cm)	(bu./ac)	(%)	(%)
19CSIT141a	RICO/BNGL//RU1202068	3.5	91	97	242	52.0	69.1
19CSIT255a	CFFY/CL261	3.0	94	102	229	48.5	67.9
19CSIT289b	14SIT818/RU1501096	3.0	86	104	229	43.5	67.0
19CSIT132a	9902028/3/BNGL//MERC/RICO/4/RU1202068	3.0	93	102	224	56.0	69.8
19CSIT419c	NPTN/RU1501096	4.0	82	101	222	53.5	66.9
19CSIT146a	CFFY/RU1202168	3.0	94	92	222	48.5	69.4
19CSIT291b	14SIT818/14CSIT314	3.0	81	105	222	45.0	67.1
19CSIT144a	CFFY/RU1202068	3.0	94	98	220	46.8	68.8
19CSIT247a	JPTR/CL261	3.0	94	91	218	61.1	68.7
19CSIT290b	14SIT818/RU1501096	3.0	86	99	217	47.0	65.1
19CSIT134a	BNGL/3/BNGL//MERC/RICO/4/RU1202068	3.0	91	98	217	51.0	67.3
19CSIT145a	CFFY/RU1202168	3.0	93	94	215	50.4	68.7
CL272a	CL272	3.0	95	108	210	n/a	n/a
CLM04b	CLM04	3.0	88	108	227	60.3	70.0
CLM04c	CLM04	3.0	83	113	202	n/a	n/a

† A subjective 1–7 rating taken at emergence, 1 = perfect stand and 7 = no stand.
a = planted on April 1; b = planted on April 30; and c = planted on May 13.

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, Arkansas, 2019.

			Days to			Milling yields	
Variety/Line	Pedigree	Seedling vigor[†]	50% heading	Plant height	Yield	Head rice	Total rice
				(cm)	(bu./ac)	(%)	(%)
19SIT0861	07PY828/TITN	3.0	85	86	272	48.8	66.8
19SIT0803	EARL/9902028//CFFY	3.0	86	105	266	n/a	n/a
19SIT0752	07SP308/NPTN	3.0	83	89	266	48.9	69.4
19SIT0745	07SP296/07SP308	3.0	85	98	266	56.2	69.0
19SIT0756	07SP308/RU0401084	3.0	79	95	263	54.3	68.0
19SIT0815	RICO/BNGL//CFFY	3.0	82	96	263	54.5	68.7
19SIT0697	CFFY/JPTR	4.0	85	100	263	49.2	64.8
19SIT0839	JPTR//9865216DH2/EARL	3.0	84	99	263	45.4	65.8
19SIT0714	CFFY/RU0502137	3.0	86	103	263	n/a	n/a
19SIT0767	07SP308/RU0502137	3.0	85	98	262	51.7	67.1
19SIT0751	07SP308/NPTN	3.0	83	99	261	n/a	n/a
19SIT0833	JPTR//EARL/9902028	3.5	86	97	261	55.8	66.3
Jupiter	Jupiter	3.0	86	99	231	n/a	n/a
Titan	Titan	3.0	83	101	230	n/a	n/a
CLM04b	CLM04	3.0	86	105	228	n/a	n/a

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

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, Arkansas, 2019.

			Days to			Milling yields	
Variety/Line	Pedigree	Seedling vigor[†]	50% heading	Plant height	Yield	Head rice	Total rice
				(cm)	(bu./ac)	(%)	(%)
19SIT0919	RU1102034/RU1201108	4.0	81	111	264	44.6	70.2
19SIT1123	DMND/LKST	4.0	78	108	261	50.7	68.0
19SIT0944	ROYJ/RU1501127	4.0	82	107	260	54.2	69.1
19SIT1041	MRMT/RU1401142	4.0	81	98	260	42.0	69.3
19SIT0947	ROYJ/RU1501127	4.0	82	106	260	55.8	69.4
19SIT1064	DMND/LKST	3.0	79	112	259	51.8	69.2
19SIT1042	MRMT/RU1201136	3.0	82	101	259	59.3	69.9
19SIT1005	RU1102131/RU0801093	3.5	81	107	258	56.0	70.6
19SIT1135	FRNS/TGRT	4.0	82	109	257	58.6	69.9
19SIT1025	RU1002128/DMND	3.0	82	108	255	57.2	69.3
19SIT1070	FRNS/TGRT	3.0	81	107	254	56.3	69.1
19SIT0967	RU0902140/DMND	3.5	80	105	252	52.3	69.5
Diamond	Diamond	3.0	81	103	251	n/a	n/a
LaKast	LaKast	3.0	79	112	198	n/a	n/a
Roy J	Roy J	3.0	86	111	189	n/a	n/a

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

Table 5. 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, Missouri, and Texas, 2019.

Entry	Pedigree	Grain type†	Days to 50% heading	Plant height	Yield	Milling yields Head rice	Total rice
				(cm)	(bu./ac)	(%)	(%)
RU1901133	TITN/RU1202168	CM	87	110	221	59.2	69.2
RU1901137	CL271/JPTR	CM	90	98	207	58.2	70.1
RU1801238	EARL/9902028//RU1202068	CM	86	99	211	61.7	70.9
RU1801097	RU1102034/RU1302045	CL	84	102	202	62.1	70.5
RU1801101	CL172/RU1102034	CL	86	102	196	63.1	71.5
RU1801169	ROYJ/RU1501024	CL	86	102	204	63.5	71.0
RU1901101	ROYJ/RU1501024	CL	82	102	205	60.4	68.9
RU1901129	RU1102131/14CSIT203	CL	87	100	204	61.3	70.9
RU1801237	JPTR/EARL	M	88	92	218	64.4	72.9
RU1801211	9865216DH2/EARL//JPTR	M	82	107	209	60.8	70.4
Lynx	Lynx	M	87	104	213	63.0	71.2
Jupiter	Jupiter	M	88	100	208	62.8	69.1
Titan	Titan	M	82	103	208	62.0	70.1
CL153	CL153	CL	88	99	195	64.7	71.8
CLL15	CLL15	CL	84	95	179	61.8	70.3
CLM04	CLM04	CM	88	109	206	64.7	70.6
Diamond	Diamond	L	85	104	198	59.7	70.9

† CL = Clearfield long-grain, CM = Clearfield medium-grain, L = long-grain, and M = medium-grain.

Progress in Hybrid Rice Breeding Program

E. Shakiba,[1] K.A.K. Moldenhauer,[1] X. Sha,[1] P.Counce,[1] R. Scott,[1] G.Bathke,[1] D.G. North,[1] V.A. Boyett,[1]
V. Thompson,[1] A. Rice,[1] O. Azapoglu,[1] and M.Q. Esguerra[1]

Abstract

The University of Arkansas System Division of Agriculture's, Rice Research and Extension Center (RREC) Hybrid Rice Breeding program has two separate activities: developing hybrid rice and hybrid rice parental lines. The hybrid breeding activities for hybrid rice production include hybrid seed (F_1) production, preliminary study and Arkansas Rice Performance Trials (ARPT), and developing restorer and male-sterile lines. Efforts for developing hybrid parental lines include a winter nursery for advance generation of different populations, developing male-sterile and restorer lines designated as female and male parents, respectively. The main focus in 2019 was to develop experimental hybrid lines and to evaluate them through preliminary and ARPT tests. These efforts continue in 2020.

Introduction

Hybrid rice is one of the most important innovations for increased rice production. (Virmani, 2003). Yield advantages of hybrid rice over conventional rice cultivars are the major motivation for developing hybrid rice cultivars. These advantages are due to a phenomenon known as heterosis (Virmani, 2003). Seed yield is the foremost goal in hybrid rice production. Heterosis effectively influences several yield components such as panicle number and spikelet number (Amandakumar and Sreehangasamy, 1984; Chang et a1., 1971, 1973; Devarathinam 1984). The first hybrid cultivar was developed in China in the mid to late 1970s, and it showed higher yield production over the conventional rice cultivars of that time (Virmani, 2003). Efforts made by the International Rice Research Institute (IRRI) to develop superior hybrid parental lines resulted in the development of several commercially successful hybrid cultivars that were used in India, Vietnam, the Philippines, Bangladesh, and Indonesia (Virmani, 2003). Arkansas is the major rice producer in the United States, and about 50% of this rice is hybrid rice (Hardke, 2017).

In last few years, the main goal of the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC) Hybrid Rice Breeding program was to develop hybrid parental lines, specifically male-sterile lines. The main focus during the last two years has been to develop and evaluate these new hybrid rice lines. Therefore, the goals in 2019 were to: 1) evaluate experimental hybrid rice in the Arkansas Rice Performance Trial (ARPT) test, 2) evaluate experimental hybrid rice in a preliminary test, 3) identify the best combinations for hybrid rice production by crossing male-sterile lines with elite cultivars and advanced rice lines, 4) develop new hybrid rice parental lines, and 5) finalize developing a new set of male-sterile lines, UAS19.

Procedures

For the first time, three experimental hybrid rice lines of H-16-2, H-16-04, and H-16-05, were tested in the 2019 ARPT test. Due to limited seed availability, the lines were tested in three locations. The results showed H-16-4 and H-16-2 outperform the conventional checks. The head rice yields were acceptable. Previous evaluations showed these lines are long-grain, low chalk with intermediate amylose content and gelatinization temperature, and good seed color and taste. We continue to evaluate our hybrid lines in 2020.

A Preliminary (heterosis) study was performed to evaluate 85 experimental hybrid rice lines in three locations: RREC (with three replications); the Pine Tree Research Center, Colt, Arkansas; and the Northeast Research and Extension Center, Keiser, Arkansas (each with two replications) in summer 2019. These lines were evaluated for several phenotypic characteristics such as seed yield, lodging, shattering, plant height, heading date, uniformity, etc. As a result, 10 experimental hybrid rice lines were selected. Presently, we are in the process of evaluating these 10 lines based on their cooking quality characteristics.

A total of 500 possible cross combinations between University of Arkansas System Division of Agriculture male-sterile lines and different pollen donors were constructed in 27 bays located in RREC. The female parent (sterile plant) from each combination was carefully harvested and threshed. The hybrid seed production among the lines varied mainly due to their heading date synchronization to the male-sterile lines. In 2020, we plan to improve hybrid seed production via new field management strategies. The hybrid seeds from those combinations with the highest amount of F_1 seed production will be used for a 2020 preliminary study.

We continued developing hybrid rice parental lines for both two- and three-line hybrid rice production. More than 4000 restorer lines from early (F_1) to advanced (F_7) were grown in field conditions in the summer of 2019. The early generations were tested via molecular analysis, while intermediate and advanced generations were evaluated based on their phenotypic evaluations such as uniformity, plant shape and height, shattering, lodging, and glabrous characteristics. Due to severe rainfall during harvesting, a number of these lines lodged while other lines remained

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[1] Assistant Professor, Professor, Professor, Professor, RREC Director, Program/Project Director, Program Associate, Program Associate, Program Associate, Graduate Assistant, Graduate Assistant, and Postdoctoral Associate respectively, University of Arkansas, Rice Research and Extension Center, Stuttgart.

standing with stiffer straw. The superior lines were harvested for further studies in summer 2020.

Final evaluation on the new set of male-sterile lines, UAS19, which included 11 isogenic lines for several agronomic traits such as phenotypic characteristics, seed set combinations, heading date, and disease resistance was performed in summer 2019. The goal was to select the superior lines that 1) possess genes associated with eating quality and non-aroma, 2) contain the semi-dwarf gene for plant height, 3) show tolerance to diseases, 4) produce good amounts of fertile seed in the winter nursery, and 5) have the ability to produce enough F_1 (hybrid) seeds. One line was selected for future hybrid rice production.

Results and Discussion

Developing hybrid rice is a challenging process. A successful breeding program should consider several criteria for hybrid production including developing hybrid parental lines suitable for commercial hybrid rice production, and developing high yield hybrid rice with good head yield, low chalk, and good milling and eating quality. Other important challenges include finding methods to maximize the production of fertile seed from male-sterile plants as wells as the production of hybrid (F_1) seed. Our strategy for the first issue is to integrate genes/quantitative trait loci associated with desirable traits and to select superior lines via extensive genotypic and phenotypic evaluation.

Our approach to developing high yielding hybrid lines with good milling and cooking quality is to 1) select superior parental lines, 2) increase the number of cross combination between male-sterile and pollen donors, and 3) test the experimental hybrid lines through preliminary ARPT and Uniform Rice Regional Nursery (URRN) trails. We placed and evaluated the first experimental hybrid lines in the ARPT in 2019, and we are planning to evaluate more lines this year in the trial.

Increasing male-sterile and hybrid seed production can be achieved via appropriate field management strategies such as the identification of a suitable winter nursery, and determination of the optimum planting date for male-sterile fertile seed production. Methods for improving hybrid seed production include 1) synchronization between male and female parent, 2) application of gibberellic acid, 3) adjusting male/female ratio in the field, and 4) implementation of an effective cross pollination method. We will continue our efforts to develop high yield hybrid rice suitable for the Arkansas rice-growing region.

Practical Applications

Our program has extensively expanded in the last four years. Our activities are divided into two categories, hybrid rice development and hybrid rice parental development. The major achievements in 2019 include 1) placing three experimental hybrid lines in the ARPT study, 2) significantly increasing hybrid rice combination , and 3) developing a new male-sterile line for two line hybrid rice production.

Acknowledgments

The authors would like to express their gratitude to Arkansas rice producers via monies administered by the Arkansas Rice Research and Promotion Board; and to the University of Arkansas System Division of Agriculture. The authors extended their appreciation to Xue Jin for marker analysis.

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Developing a New Environmental Genic Male-Sterile Line

E. Shakiba,[1] KAK Moldenhauer,[1] D. North,[1] V. Boyett,[1] and A. Rice[1]

Abstract

Successful large-scale hybrid rice seed production relies on developing suitable male-sterile lines. The University of Arkansas System Division of Agriculture's Rice Research and Extension Center, Hybrid Rice Breeding program developed a new environmental genic male sterile (EGMS) line for two-line hybrid rice production. The new EGMS line contains genes/quantitative trait loci associated with desirable phenotypic and cooking quality characteristics. It produces acceptable male-sterile seeds and has been tested for hybrid rice production.

Introduction

Hybrid rice is one of the important agricultural innovations of the 20th century (Dhindsa, 2014). Hybrid rice is defined as F_1 seeds resulting from a cross between two genetically distinct parents (Virmani., 2003). Superiority in yield production of the hybrid rice cultivars compared to the conventional rice cultivars is due to a genetic phenomenon known as heterosis that affects several yield components (Amandakumar and Sreehangasamy, 1984; Chang et a1., 1971, 1973; Devarathinam, 1984).

Based on an agronomical point of view, heterosis could be positive for some desirable traits such as yield and tolerance to salinity and diseases, or negative such as increasing plant height. Our aim is to develop hybrid rice parental lines to promote favorable traits and integrating genes associated with desirable traits using marker-assisted selection and extensive phenotypic evaluation.

Effective commercial hybrid seed production depends on an apposite male-sterile parent assigned as female parent. Generally, there are two types of male sterile, Cytoplasmic male sterile used for three-line hybrid production and environmental genic male sterile line (EGMS) applied in two-line hybrid rice production. Pollen sterility occurs in EGMS lines when specific gene(s) are influenced by certain environment conditions such as photoperiod (PGMS), temperature (TGMS), or a combination of photoperiod and temperature (PTGMS) (Virmani, 2003).

Several male-sterile lines were developed by the Hybrid Rice Program. Despite the high percent of sterility in these male-sterile lines, the cooking quality of the hybrids derived from these lines did not meet the desirable cooking quality required for the typical southern U.S. long-grain rice market. Moreover, these hybrid lines showed severe lodging and seeds were chalky. Our objective in this project was to develop a male-sterile plant that is semi-dwarf, rice blast resistance, and with good milling and cooking characteristics such as intermediate amylose content, intermediate gelatinization temperature, non-aroma, and low chalk.

Procedures

A population was made by crossing a University of Arkansas System Division of Agriculture developed EGMS male-sterile line, 236s, and Cocodrie. A molecular study showed that 236s possessed the genes for semi-dwarf plant type, long-grain, low amylose content, non-aroma, and was segregating for low and intermediate gelatinization temperature. In addition, 236s is susceptible to the rice blast disease. The process of developing the line is as follows (Table 1):

2013–The initial crosses were made in fall 2013 and back-crossed to the 236s in 2014.

2015–A total of 589 BC_1F_2 plants were grown in the field condition in the summer of 2015, and 49 single plants were selected based on the phenotypic and genotypic evaluations, the single plants were ratooned and placed in the greenhouse condition to get BC_1F_3 seeds.

2016–The selected BC_1F_3 lines were grown, and were evaluated through an extensive phenotypic analysis such as plant height, plant type, number of panicles per plant, stiff straw, overall panicle exertion, and percent sterility of the primary panicles. A total 190 BC_1F_3 plants were selected, ratooned and placed in a greenhouse in an environmental condition required for seed production. Meanwhile, the lines were tested for two other criteria, one was it amount of fertile male-sterile seed production, and the other was its ability to cross with pollen donors to produce hybrid (F_1) seeds.

2017–BC_1F_4 lines were grown in the field condition in summer of 2017. Beside the phenotypic characteristics mentioned above, these lines were evaluated for seed size, panicle exsertion, line uniformity and heading date. As a result, 49 BC_1F_4 lines were selected and BC_1F_5 seeds from these lines were obtained via the process mentioned above. Furthermore, we conducted a preliminary study to evaluate yield and seed quality of experimental hybrid lines resulting from the male-sterile and selected male parents.

2018–All 49 BC_1F_5 were grown and evaluated in summer, and all off-type plants within each line were removed. The BC_1F_6 seeds were sent to the Puerto Rico winter nursery for the seed production. In addition, the yield test of experimental hybrid seeds from these lines was continued.

2019–Of the 49 BC_1F_6 lines, 11 lines were selected based on their male-sterile seed production. The BC_1F_7 lines were evaluated based on their uniformity, heading date, plant shape, plant height,

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[1] Assistant Professor, Professor, Program Associate, Program Associate, and Graduate Student respectively, Rice Research and Extension Center, Stuttgart.

flag leaf shape, and disease resistance. As a result, one line was selected as a new male-sterile line.

Results and Discussion

The new male-sterile line UAS19-9 is a highly sterile, semi-dwarf, with an erect plant type and average plant height of 87 cm. It shows good lodging and shattering resistance. The panicles have an open shape with more than 90% panicle exsertion. The flag leaf is glabrous and green in color, with a 32.8-cm length and 17.6-mm width. The sterile line showed good male-sterile seed production as well as good combining ability. The leaf angle of the flag leaf is intermediate after heading. The ligule is 5.8 mm long, white in color with acute shape, and the collar color is pale green. An average panicle length is 22.2 cm. The average number of days from emergence to 50% heading is 81 as compared to titan 81 and other cultivars (Table 2). The seeds are non-aromatic, brown in color, long-grain with rough rice dimensions of 8.73-mm length, 2.42-mm width, 1.86-mm thickness, and a length-width ratio of 3.60 mm. The line UAS19-9 possesses genes associated with intermediate amylose content, and intermediate gelatinization. Furthermore, the male-sterile line has the *Pi-k*^{s} gene associated with blast resistance (Table 2). It shows moderate susceptibility to false smut.

Practical Applications

We developed a new EGMS male-sterile line, UAS19-9 suitable for two-hybrid rice production. The male-sterile line has genes/quantitative trait loci associated with agronomic traits. The lines were evaluated for hybrid rice production by crossing the male sterile with different males and the results showed the male sterile potential for developing commercial hybrid rice cultivars.

Practical Applications

The release of ARoma 17 provides producers with a high yielding, Jasmine-type aromatic, mid-season, long-grain rice. The major advantages of ARoma 17 are its high yield potential in the specialty aromatic market. Research is ongoing to identify and release new, improved aromatic varieties for the producers to grow and for the increasing consumer demand.

Acknowledgments

The authors would like to express their gratitude to Arkansas rice producers via monies administered by the Arkansas Rice Research and Promotion Board; and to the University of Arkansas System Division of Agriculture. The authors extend their appreciation to Xue Jin for marker analysis.

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Table 1. Process of developing the male-sterile line UAS19-9.

Year	Pedigree	Generation	Note[a]	Location
2013	Cross	-	236s x CCDR	RREC[b]
2014	Space planting	F_1	Seed increase	RREC
2015	Progeny Rows	F_2	MS, PHS	RREC
2016	Progeny Rows	F_3	MS, PHS,CA,PS	RREC
2017	Progeny Rows	F_4	MS, PHS,CA,PS, HE	RREC
2018	Progeny Rows	F_5	MS, PHS,CA,PS, HE,MSE	RREC
2018	Progeny Rows	F_6	MSE	Puerto Rico
2019	Progeny Rows	F_7	MS, PHS,CA,PS, HE,MSE	RREC

[a] MS = molecular evaluation; PHS = phenotypic evaluation; CA = combining ability; PS = percent of sterility; HE = Hybrid production; MSE = male-sterile seed production.

[b] RREC = University of Arkansas System Division of Agriculture's Rice Research and Extension Center.

Table 2. Genetic analysis of UAS19-9, its parental lines, and two rice cultivars.

	Cooking quality							
Line	Amylose content	Gelatinization temperature	Aroma	Grain size	Plant height	50% heading	Flag leaf	Blast resistance
UAS19-9	intermediate	medium	none	long	97	83[a]	glabrous	*Pi-k*^{s}
Jupiter	low	low	none	medium	99	95[b]	glabrous	*Pi-k*^{s}
Lagru	Intermediate	medium	none	long	110	89[a]	glabrous	Susceptible
Cocodrie	Intermediate	medium	none	long	110	88[b]	glabrous	*Pi-k*^{h}
236s	low	low	none	medium	95	110[a]	glabrous	*Pi-k*^{s}

[a] Data was recorded based on field observation in Stuttgart, Arkansas during 2018 and 2019.

[b] Data is collected from the 2016 Uniform Regional Rice Nursery trial.

Development of Aromatic Rice Varieties

D.K.A. Wisdom,[1] K.A.K. Moldenhauer,[1] X. Sha,[1] J.M. Bulloch,[1] V.A. Boyett,[1]
V.I. Thompson,[1] S.B. Belmar,[1] C.D. Kelsey,[2] D.L. McCarty,[1] and C.H. Northcutt[1]

Abstract

Consumers in the United States are exploring new food products and enjoying the farm-to-table experience. Interest in aromatic rice has increased with the advent of nouveau cuisine and the 'identity preservation' ideals of the farm-to-table movement. Sales of aromatic rice have led rice imports to increase over 30% in the last ten years. The University of Arkansas System Division of Agriculture Aromatic Rice Breeding Program at the Rice Research and Extension Center (RREC), Stuttgart, Arkansas, was implemented to develop aromatic rice varieties for the southern rice-producing regions. Evaluating cultural practices is essential for selecting advanced lines in the breeding program as well as for growers. Information regarding successful cultural practices for aromatic rice varieties is limited in the southern United States growing regions, and especially for Arkansas.

Introduction

Aromatic varieties imported from Thailand, India, Pakistan, and Vietnam are expected to make up the majority of the record 24 million cwt long-grain imports to the United States in 2019/2020 (USDA-ERS, 2019a). Approximately 133,800 tons of rice were imported to the United States from Thailand, our largest supplier of imports, in 2019 (USDA-ERS, 2019a). Over the past 10 years (Market Years 2009/2010 to 2019/2010), rice imports from India and Thailand have increased 84% and 21%, respectively, with most of the imported rice being premium aromatic (USDA-ERS, 2016 and 2019b). United States consumers are purchasing more aromatic and/or specialty rice. United States producers find it difficult to grow the true jasmine and basmati varieties due to environmental differences, photoperiod sensitivity, fertilizer sensitivity, and low yields. Adapted aromatic rice varieties need to be developed for Arkansas producers which meet the taste requirements for either jasmine or basmati.

Procedures

The University of Arkansas System Division of Agriculture Aromatic Rice Breeding Program at the Rice Research and Extension Center (RREC), Stuttgart, Arkansas, has collected parental material from the U.S. breeding programs and the USDA World Collection. Crosses have been made to incorporate traits for aroma, yield, improved plant type, superior quality, and broad-based disease resistance. The winter nursery in Puerto Rico is being employed to accelerate generation advance of potential varieties for testing in Arkansas during the summer of 2020.

Results and Discussion

In 2019, selections were made from approximately 2,620 lines in 111 populations grown in the F_3, F_4, and F_5 nurseries. The parents in these crosses were selected for their aromatic seed quality or high yield potential. Samples from 88 heterozygous lines from 33 F_4, F_5, F_6, and F_7 populations have been submitted to undergo molecular marker analysis. Lines that have the preferred markers for aroma, cooking quality, and blast resistance will be entered in yield trials in 2020.

In a two-replication preliminary trial planted in 2019, 24 aromatic lines were evaluated for yield. In the Aromatic Stuttgart Initial Test (ASIT), which has four replications, 21 aromatic lines were evaluated for yield and potential release. In the four-replication Aromatic Advanced Yield Trial (AAYT), 30 aromatic experimental lines were evaluated for yield and potential release. Seed from the top-yielding 12 experimental lines with preferred plant types from the ASIT and AAYT were milled and cooked in a taste test during the winter 2020. The four experimental lines that were chosen as having the best flavor and aroma have been entered in the Arkansas Rice Performance Trials (ARPT) and are being grown in increase plots in 2020. Five aromatic experimental lines have also been entered in the 2020 Uniform Regional Rice Nursery (URRN).

In 2019, five jasmine-type experimental lines were entered in the URRN. The Arkansas mean yields for ARoma 17 and the five lines were as follows: ARoma 17, 182 bu./ac; EXP18105, 192 bu./ac; EXP18109, 200 bu./ac; EXP19189, 192 bu./ac; EXP19206, 191 bu./ac; and EXP19231, 150 bu./ac. The URRN Arkansas two-year average yields were: ARoma 17, 177 bu./ac; EXP18105, 187 bu./ac; and EXP18109, 203 bu./ac.

Four experimental lines were also entered in the 2019 ARPT. The mean yields for ARoma 17, Jazzman-2, and the four lines were as follows: ARoma 17, 178 bu./ac; Jazzman 2, 159 bu./ac; EXP18105, 179 bu./ac; EXP18109, 176 bu./ac; EXP19206, 179 bu./ac; and STG16L-172, 170 bu./ac. The ARPT two-year average yields were: ARoma 17, 171 bu./ac; Jazzman-2, 150 bu./ac; EXP18105, 172 bu./ac; and EXP18109, 174 bu./ac.

One experimental line being considered for release is EXP19231 which has a pedigree including Jazzman, a short-

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[1] Program Associate, Professor, Professor, Program Associate, Program Associate, Program Technician, Program Technician, Program Associate, and Program Technician, respectively, Rice Research and Extension Center, Stuttgart.

[2] Program Technician, Extension Plant Pathology, Department of Plant Pathology, Rice Research and Extension Center, Stuttgart.

season experimental line from the University of Arkansas System Division of Agriculture, and Taggart. The line EXP19231 has excellent flavor and will continue to be examined in the ARPT and URRN in 2020. Head rows of EXP19231 will be planted for seed increase in 2020.

Practical Applications

The project develops new aromatic lines with improved performance for the Arkansas and mid-South producers to meet U. S. consumers' growing demand for locally grown aromatic rice to feed their families.

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. We thank Xue Jin for assistance in conducting marker analysis.

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Field Efficacy of *Trichoderma*-TM17 against Sheath Blight of Rice

Y.A. Wamishe,[1] T. Mulaw,[1] T. Gebremariam,[1] S.B. Belmar,[1] and C.D. Kelsey[1]

Abstract

Rice sheath blight, caused by the soilborne fungal pathogen *Rhizoctonia solani* AG-1A, is an economically important disease in rice. Nearly 57% of Arkansas rice fields receive fungicides to suppress one or more rice diseases including sheath blight. Disease control using chemicals leads to increased risk to our environment. As an alternative option, biological control methods have gained interest in modern agriculture. As a result, several species in genus *Trichoderma* are known to be effective against fungal plant diseases. In this preliminary study, an experiment was designed in 2019 to test an isolate of *Trichoderma atroviride* (TM17) for seed dressing, and as a pre- and post-inoculation treatment to suppress sheath blight of rice. Seeds of long-grain rice, CL163 were soaked in a suspension of TM17, adjusted to 10^9 per ml spore concentration and dried under a sterile hood overnight before planting. Pre-inoculation treatment was sprayed on foliage at panicle initiation a week before *R. solani* AG-1A was inoculated. The post-inoculation treatment was applied a week after inoculation with 10^9 per ml spore concentration as in the seed treatment. Results showed that disease ratings were lower in foliage treated plots (pre- and post-inoculation treatments) than in the untreated control plots. Grain yields were also significantly higher in these plots than the untreated check. Plots planted with treated seeds showed a slightly lower incidence of disease than the control plots. Nevertheless, yield differences were not significantly different. The experiment should be repeated, refining the seed dressing method and on methodologies, particularly towards establishing TM17 in rice canopy throughout the season.

Introduction

Rice sheath blight (*Rhizoctonia solani* AG-1A) causes damage to rice in various regions of the world. Grain yield losses due to sheath blight have been reported as high as 45%, depending on rice growth stage, timing of disease onset and favorable conditions (Kumar et al., 2009). However, in Arkansas where more than half of the U.S. rice is produced, the yield loss can reach up to 15%. In a rice production system where excessive seeding and nitrogen rates are practiced and weather conditions are favorable, severe sheath blight is expected, causing adverse yield loss particularly when the crop is downed by resulting weak stems. Moreover, inadequate crop management, and the susceptibility level in most rice cultivars favor the disease to progress (Zheng et al., 2013). Although extensive evaluations of rice germplasm have been conducted towards developing rice cultivars that are highly resistant to this disease, there are still no cultivars with a significant degree of resistance (Srinivasachary et al., 2013). As a result, most of the management strategies utilized to suppress sheath blight in rice include the use of fungicides.

Trichoderma is a genus of fungi in the family Hypocreaceae. Some species are known for their antagonistic activities or competitive behaviors against several plant pathogens, including *R. solani* (Harman, 2006). A number of studies were performed in vitro or in vivo in greenhouses (Naeimi et al., 2010). Some studies indicated that biological control with *Trichoderma* may be effective under reduced inoculum and lower sheath blight disease pressure in rice (Das and Hazarika, 2000; Naeimi et al., 2010). A few other studies reported some levels of efficiency under field conditions using various types of application methods such as foliar spray and seed treatments. The main objective of our study was to assess the efficacy of the endophyte *Trichoderma* isolate, TM17 in suppressing sheath blight in rice under flooded field conditions. The isolate was obtained from surface sterilized rice seeds plated on agar medium in our laboratory, so is believed to be an endophyte in rice seed.

Procedures

Source of the *Trichoderma atroviride* (TM17) Isolate

An isolate of *Trichoderma* sp. designated as TM17 was originally isolated from rice seeds at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC) near Stuttgart, Arkansas, and is considered to be an endophyte in rice. The isolate was selected based on its biocontrol and plant growth promoting activities as determined in our previous preliminary greenhouse studies on sheath blight fungus (*R. solani* AG-1A) and the rice blast pathogen (*Magnaporthe oryzae*).

Culture Preparation for Foliar Treatment and Seed Dressing

An isolate TM17 was cultured in petri dishes on Potato Dextrose Agar (PDA) and incubated at 25 °C for 7 to 10 days. Cultures of TM17 were washed off using sterile distilled water. Standard procedure for fungal spore count was used to determine spore count using hemocytometer. A 10^9 per ml spore concentration was used both for seed dressing and pre-and post-inoculation treatments.

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[1] Associate Professor, Program Technician, Program Associate, Program Technician, Program Technician, respectively, Rice Research and Extension Center, Stuttgart.

Land Preparation and Field Plot Design

Field plots were designed to compose four treatments in addition to untreated control, each with 4 replications in completely randomized block design. Each plot size was 15 ft by 5 ft. The area for plots was rototilled before planting. A sheath blight susceptible long-grain rice variety, CL163 was drill planted on 15 May 2019 at a maximum seeding rate to increase rice canopy and encourage sheath blight inoculum to cause disease symptoms. Seeds of the same variety were used for seed dressing treatment. Pre-and post-emergence weeds were managed using the recommended herbicides and nitrogen fertilization (urea) was deliberately increased from 150 to 180 units per acre rate to enhance sheath blight disease development and progress. The four treatments included:1) untreated control; 2) Pre-inoculation; 3) Post-inoculation and 4) Seed dressing.

Application of TM17 to Rice Seeds for Plot Planting

Rice seeds were surface sterilized with 1% (v/v) hypochlorite solution and rinsed repeatedly with sterilized water. Seeds were soaked in a spore suspension of TM17 at a concentration of 10^9 spores per ml. The seeds were left on a shaker for two hours. After straining, seeds were dried overnight on a sheet of clean paper in a sterile hood. Seeds for control were treated similarly but treated with sterile water instead of TM17 suspension. Finally, seeds were drill planted.

Application of TM17 to Rice Foliage

The pre-inoculation treatments were applied a week before inoculating the field with cereal based culture of *R. solani* AG-1A and the post-inoculation treatment a week after inoculation with a spore suspension of TM17 at a concentration of 10^9 spores per ml. A MudMaster™ model MM2013 was used to deliver the spore suspension. Control plots were neither seed- nor foliar-treated with TM17.

Data Collection

Sheath blight severity was evaluated on its progress vertically up to the canopy using the 0 to 9 scale where 0 represented no disease and 9, severe disease reaching panicles. Horizontal disease progress was estimated from the middle rows using percentages of rice plants in three feet length. Disease data were collected 28 days after inoculation and two weeks before harvest. Grain yield and disease data were statistically analyzed using PROC GLM procedure in SAS 9.4 (SAS Institute, Inc., Cary N.C.).

Results and Discussion

Both vertical and horizontal disease ratings were consistent in showing the pre- and post-inoculated plots as healthier than those planted with treated seeds or the control check. Likewise, grain yield also showed a similar trend. Although the seed treatment appeared to show better performance in sheath blight ratings than untreated control, differences were not significant enough to show yield differences. Results showed no significant difference between the pre- and post-inoculation treatments in suppressing the *Rhizoctonia solani* AG-1A. Similarly, yield differences were not significant between the pre- and post-inoculated plots. Trends in disease ratings are not different in disease data recorded 21 days after inoculation or those near harvest (Fig. 1). There was only a 5% yield increase for treated seeds over the untreated control; whereas up to 15% yield increase was observed by both pre-treated and post-treated plots (Fig. 2).

When observing the growth of TM17 with *R. solani* AG-1A on a plate, it appeared to be an aggressive competitor. Although mechanisms such as antibiosis, mycoparasitism, hyphal interactions, and enzyme secretions are used to combat fungal pathogens in plants, the mechanism for TM17 appears more competitive. Some species of *Trichoderma* are reported as highly interactive in plants, soil, root systems and foliar environments, however a more detailed study is required to understand the biology of TM17 when used as a biocontrol to suppress rice diseases such as sheath blight and blast in rice often produced in a flooded situation. Moreover, the seed dressing treatments require refinement in order to carry adequate amount of spores and mycelia to adhere to seeds. More research is needed to determine a working concentration, plant stages for treatment, best methods of delivery, and suitable environmental conditions that help the species to establish better outside of its natural ecosystem.

Practical Applications

Biological control options have recently gained more interest as safe components in plant disease management. However, the challenge in most cases has been finding ways to establish the biological agents outside of their ecosystem and to promote their survival for an entire season in order to extend protection of crops. The *Trichoderma* sp. TM17 in this study was first isolated from rice seeds and is believed to be an endophyte in rice. Although, our research is in its infancy, previous in vitro laboratory and in vivo greenhouse tests suggest high suppressing effects on blast and sheath blight pathogens in rice. The field data in this study also indicated TM17's potential in suppressing sheath blight when applied prior or after rice was artificially inoculated. However, more work is needed to refine methodologies, particularly towards establishment in rice canopy throughout the season.

Acknowledgments

The authors appreciate the funding support for this project by the Arkansas Rice Research and Promotion Board. Support also provided by the University of Arkansas System Division of Agriculture.

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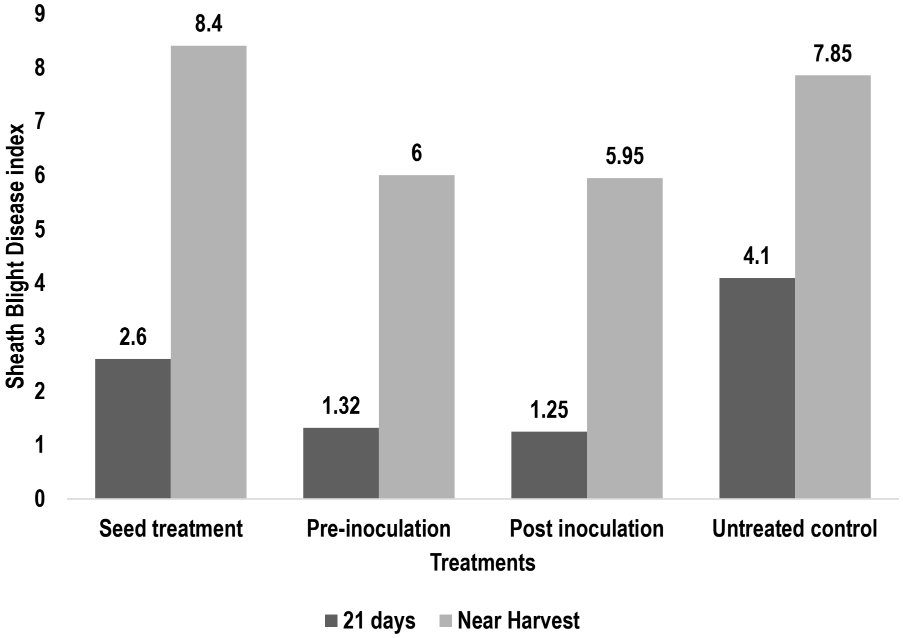

Fig. 1. Differences in sheath blight indices as combined from vertical (0 to 9 scale where 0 represented no disease and 9, severe disease reaching panicles) and horizontal (estimated from the middle rows using percentages of rice plants in three feet length) disease progress ratings from test plots of 4 treatments where a *Trichoderma* isolate, TM17 was tested for its biocontrol activity to suppress sheath blight in rice. LSD 0.05 = 1.80, 2.56 at 21 days after inoculation and near harvest, respectively.

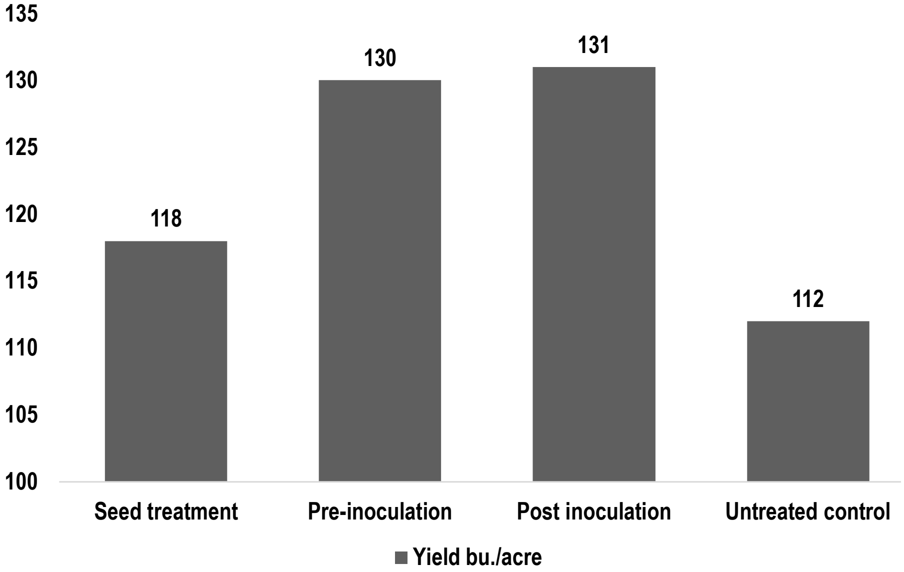

Fig. 2. Differences in grain yield from test plots of 4 treatments where a *Trichoderma* isolate, TM17 was tested for its biocontrol activity to suppress sheath blight in rice LSD 0.05 = 17.29.

Rice Breeding and Pathology Technical Support

S.B. Belmar,[1] C.D. Kelsey,[1] K.A.K. Moldenhauer,[1] and Y. Wamishe[1]

Abstract

Development of disease resistant rice is one of many goals rice breeders work on at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC) near Stuttgart, Arkansas The center's plant pathology group assists by screening preliminary to advance breeding entries for disease reaction under greenhouse and field conditions. Breeding materials are evaluated after using artificial inoculum for sheath blight at the RREC and blast disease at the RREC and the University of Arkansas System Division of Agriculture's Pine Tree Research Station (PTRS) near Colt, Arkansas. Both sheath blight and blast inocula are produced in the laboratory and applied to plants using specific protocols for each disease. Sheath blight is screened under field conditions, but blast screening utilizes both greenhouse and field environments. The major objectives of this technical support are to provide data that not only helps breeders remove the most susceptible lines early in their program, but also to support advancement of lines or transfer of genes for resistance into adapted and high yielding varieties. The breeding and pathology technical support group assists extension plant pathology programs with applied research to manage diseases that prevail in rice fields, as well as, collaborative interdepartmental, industry, and multi-state research endeavors.

Introduction

Rice breeders and pathologists work together to develop varieties having desirable disease resistance along with desired agronomic traits. Disease evaluation of rice against major diseases begins in the early generations of plant selection and is a required activity for a successful breeding program. Lines having some potential traits that do not meet the desired levels for release may become parents to develop other new varieties.

Rice blast, caused by *Magnaportha grisea* (T.T. Herbert) M.E. Barr, is still an important disease. Emphasis is given to evaluate breeding materials for both leaf and neck/panicle blast. Rice seedlings from the greenhouse are used to evaluate leaf blast while mature plants in the field determine a plant's resistance to neck/panicle blast. Screening plants for blast requires desired environmental conditions prior to and after inoculation for the pathogen to cause disease.

Sheath blight (*Rhizoctonia solani* Kuhn), another problematic fungal disease of rice, is evaluated on fully grown plants in the field at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC) near Stuttgart, Arkansas. While no qualitative resistance to this pathogen exists, knowledge of whether a variety can tolerate infection through reduced spread of the pathogen is valuable to breeding programs. Inoculum production to enhance sheath blight disease in plots requires a massive amount of a corn/rough rice seed mixture as a carrier of sclerotia and mycelia of the fungus used to start the disease.

Procedures

Greenhouse Evaluation of Breeding Materials for Blast Resistance

Entries of the Arkansas Rice Performance Trials (ARPT), Aromatics, Imidazolinone ARPT (IMI-ARPT), Imidazolinone Stuttgart Initial Test (IMI-SIT), and Uniform Regional Rice Nursery (URRN) were evaluated as hill plots for their resistance to leaf blast. Tests were replicated to generate six disease observations per entry. Over 1200 flats of soil were prepared to produce 3 to 4 leaf seedlings. Each replicate was spray inoculated using individual spore suspensions made of *M. grisea* races: IB1, IB49, IC17, IB17, and IE1K. Inoculum production and disease establishment followed earlier described procedures (Kelsey, et al., 2016). Disease data were collected in 7 to 10 days after inoculation using two rating scales. Disease severity rating used the 0 to 9 scale where 0 is healthy tissue and 9 is elongated necrotic tissue. Incidence scale estimated relative lesion coverage on the leaf blades where 1 is single leaf or lesion to 100, all leaves necrotic with multiple lesions. Testing of entries in the SIT, IMI-SIT and Preliminary Test (Prelims) used a bulk spore suspension that was prepared by combining the four races previously used as individual suspensions. Entries were tested separately with IE1K due partially to the aggressiveness of this race on rice.

Field Evaluation of Breeding Materials for Blast and Sheath Blight

The blast disease nursery at the University of Arkansas System Division of Agriculture's Pine Tree Research Station (PTRS) near Colt, Arkansas was established on 17 May in a secluded area having a forested border on three sides of the test. The study included 336 entries from URRN/ARPT collection in six replicated hill plots surrounded by a spreader mixture of susceptible lines to encourage spore multiplication and disease spread within the nursery. Nursery started as a flooded paddy but later changed to upland conditions before inoculating plants with the pathogen. Around 100 gallons of corn chops/rough rice media were created using a mixture of IB17, IB1, IC17 and IB49 pathogen races. Over the course of three field visits: 13 June (tillering), 8 August (boot split), and 26 August (panicle) semi-dried and freshly made seed

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[1] Program Technician, Program Technician, Professor, and Associate Professor, respectively. Rice Research and Extension Center, Stuttgart.

media was broadcasted to inoculate rice plants. A month after inoculation, plants were rated for head and panicle blast development with a count of infected panicles per hill plot.

In testing for sheath blight tolerance, a nursery at the RREC was planted on 30 April in two adjacent bays. Each bay contained four reps of entries for ARPT, Aromatics, IMI-ARPT, SIT, IMI-SIT, Prelims, and URRN for a total of 1068-hill plots per rep. From 12 July to 13 July, plants (at panicle initiation stage) in one bay were hand inoculated with relatively faster growing *R. solani* isolates (approximately 36 gallons), at the rate of 24g (1 oz) per six hill plot row. Plants in the other bay were also hand inoculated with a mixture of two slower growing fungal isolates. About five weeks later, fungal disease assessment of each hill plot was made with a rating scale of 0 (no disease) to 9 (severe disease that surpassed the flag leaf).

Assistance to Extension Rice Pathology

Breeding pathology technical support assisted with the planting of five field experiments designed to collect data for rice disease control of sheath blight and early season seedling disease. All tests screened products for control of sheath blight or for seedling diseases used as seed treatments. These tests utilized artificial inoculation with *R. solani* and fungicide application to 136 rice plots. Twenty-four products were tested for control of sheath blight. The seedling study collected data of stand count and seedling height. A fungicide spray coverage study on sheath blight and false smut consisted of 72 plots to evaluate chemical application timing and spray volumes of fungicides for management of these diseases. Over 1,000 breeder plots that contained preliminary and advanced breeding lines were scouted for major rice diseases that occurred naturally in the field.

Results and Discussion

Disease assessment of rice for resistance/tolerance to sheath blight and blast was completed for the breeding program. For each of the tests, several tolerant entries to sheath blight were identified (Table 1). Use of slower colonizing isolates of *R. solani* continued to meet the objectives for sheath blight screening since more than 50% of the entries were classified as susceptible. The field blast nursery showed several promising entries from URRN and ARPT to be tolerant to head/panicle blast (Table 1). Overlapping tolerant entries for both diseases showed four for ARPT, but eight entries from the URRN test (Table 1). Although this outcome was encouraging, continued evaluation is needed to confirm results. Additional refinement of establishing the pathogen under field conditions continues for development of the blast epidemic.

Of the 966 experimental lines tested for leaf blast in the greenhouse with individual races of blast, several were rated as disease tolerant (Table 2). Collection of incidence data along with severity data was helpful toward distinguishing test entries that have potential for advancement from those identified as possible mechanical seed mixture or due to segregation.

The breeding–pathology technical support group has significantly contributed towards the success of research activities in breeding and extension pathology programs. The assistance covers studies in laboratory, greenhouse, and field, as well as, collaborative research with industries and interdepartmental research.

Practical Applications

The rice breeding-pathology technical support group provides disease data to the breeding program to minimize the most susceptible materials from advancing and allows selection and development of new high yielding cultivars with anticipated levels of disease resistance. In addition, technical support is core in extension plant pathology with involvement in applied research. Data generated by the extension pathology program provides dependable and practical information for rice producers in Arkansas and other rice-producing states. This technical support group is actively working with breeders and the extension pathology program to improve rice productivity.

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. We also appreciate the help of Tibebu Gebremariam in his operating of field equipment.

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Table 1. Number of entries rated disease tolerant in 2019 field disease nurseries.

Test	Total entries	Sheath blight with "slower" growing isolate[b]	Head/panicle blast[c]	Both diseases
ARPT[a]	69	22	12	4
URRN	232	58	26	8
Aromatics	83	30	na[d]	na
SIT	125	82	na	na
IMI-ARPT	66	16	na	na
IMI-SIT	164	65	na	na
Prelims	227	129	na	na

[a] Arkansas Rice Performance Trials (ARPT), Uniform Regional Rice Nursery (URRN), Aromatics, Imidazolinone ARPT (IMI-ARPT), Imidazolinone Stuttgart Initial Test (IMI-SIT).

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

[c] Four races bulked together for blast field screening. Rating scale of 0 (no disease) to 9 (dead plant) was used. Up to a "4" rating was tolerant.

[d] Not available.

Table 2. Number of entries rated disease tolerant[a] for 2019 greenhouse leaf blast testing.

Test	Total Entries	IE1K	IC17	IB17	IB49	IB1
ARPT[b]	69	24	25	18	14	17
URRN	232	70	97	96	64	96
Aromatics[c]	83	32	37	31	19	50
IMI-ARPT	66	16	14	17	9	9
			Bulked across the individual races			
SIT	125	48	41			
IMI-SIT	164	38	54			
Prelims	227	103	78			

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

[b] Arkansas Rice Performance Trials (ARPT), Uniform Regional Rice Nursery (URRN), Aromatics, Imidazolinone ARPT (IMI-ARPT), Imidazolinone Stuttgart Initial Test (IMI-SIT).

[c] Collectively includes Arkansas Yield Trials, Stuttgart Initial Trials and Preliminary varieties.

Evaluation of Contemporary Rice to Straighthead, a Physiological Disorder of Unknown Cause

Y. Wamishe,[1] J. Hardke,[2] and T. Gebremariam[1]

Abstract

Although straighthead has been known to affect only a small percentage of the Arkansas rice acreage, considerable acreage is drained every year to manage straighthead thus incurring additional costs to rice production. The main purposes 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 reevaluate the older varieties which are still in production because of their response consistency, and to assess the susceptibility of advanced breeding lines prior to release for commercial production. Three different bays, each with 35 (30 test entries and 5 control) were established in experimental fields of the University of Arkansas System Division of Agriculture's Rice Research and Extension Center, Stuttgart, Arkansas. The 1st two bays received MSMA (monosodium methanearsonate). One of these two bays was kept flooded to at least a 4-inch depth from 5-leaf stage to maturity and the other was flushed intermittently. A third control bay received no MSMA but was kept flooded to at least a 4-inch depth from 5-leaf stage to maturity. The entries were visually examined for straighthead symptoms at dough stage before the flood was drained. None of the control or the test entries showed straighthead symptoms in the MSMA-free bay. The bay that received MSMA and kept with permanent flood showed 7 very susceptible (VS), 3 susceptible (S), 14 moderately resistant (MR), and 4 resistant (R) cultivars indicating clear differences in varietal response to MSMA. Two entries did not emerge and were missing. In the bay that received MSMA and was treated with intermittent flooding, only those that rated VS above showed mild straighthead symptoms on panicles of 2 to 5 tillers which appeared late in the season. The experiment will be repeated in 2020 to include more advanced breeding lines.

Introduction

Straighthead in rice (*Oryza sativa*) is one of the oldest reported physiological disorders of unknown cause. Straighthead causes rice florets to be sterile and hence, panicles to be blank with distorted lemma and palea, leading to significant declines 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 rice fields, symptoms appear each time rice is cultivated unless cultivars with some levels of resistance are used. In a field planted with a susceptible rice, straighthead may develop at some point during the season unless the "drain and dry" strategy is applied to alleviate the problem with adequate aeration. To reduce the impact on grain yield, the drain and dry strategy should be implemented at appropriate timing, usually before the beginning of the reproductive stages.

The draining and drying management strategy for straighthead is often difficult when field sizes are big and water resources are limited. This means straighthead management requires additional cost for re-flooding. To producers, cultivar resistance is cheaper and user-friendly. Rice varieties can be resistant (R), moderately resistant (MR), susceptible (S), moderately susceptible (MS) and very susceptible (VS) 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 straighthead results in an adverse loss in grain yield. Regardless of the cost and inconvenience, most Arkansas acreages known to have straighthead are drained and dried. The main objectives of this study were to provide rice producers with the most current information regarding the susceptibility of the new rice varieties and hybrids for their reaction to straighthead, to reevaluate the older varieties which are still in production because of their consistency in response, and to assess the susceptibility of advanced breeding lines before they are released for commercial production.

Procedures

Field Evaluation of Rice Cultivars for Resistance or Tolerance to Straighthead

The test was carried out in a field plot at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center, Stuttgart, Arkansas (RREC) which was established over a decade ago to evaluate rice germplasm response to straighthead. The selected area was measured out and rototilled. A gallon per acre rate of MSMA (monosodium methanearsonate, 6 lb ai/ac) was sprayed using a mud master at 20-GPA (gallons of water per acre) rate and was carefully rototilled again to incorporate the arsenate compound with the soil. A couple of hours from incorporation, 35 rice entries consisting of 19 conventional cultivars (both older and new), 3 Rice Tech hybrid rice varieties, and 8 advanced breeding lines were planted (Table 1). Well known highly susceptible varieties (Cocodrie and CL151), resistant varieties, Taggart and RT CLXL745 and a moderately

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[1] Associate Professor and Program Associate, respectively. Department of Plant Pathology, Rice Research and Extension Center, Stuttgart.

[2] Associate Professor, Crop, Soil, and Environmental Sciences, Rice Research and Extension Center, Stuttgart.

resistant variety (Francis) were included in the test as control. All rice test and control entries were planted in hill plots in 4 replications. The 5 rice varieties used as control were planted before and after every 10 test entries. Two similar bays with the same number of rice entries were side by side. One of these bays was kept flooded to at least a 4-inch depth starting from 5-leaf stage to maturity and the other was flushed intermittently. In the latter bay, intermittent flushing followed a week of dryness until the ground showed cracks. Another bay planted with the same number of entries but without MSMA applied was established further from the straighthead field to serve as an MSMA-free control. This bay was kept flooded similar to the one described above. Visual comparisons were made between the three bays. However, a 0 to 9 scale where 0 is no straighthead and 9, all heads with symptoms was used to evaluate the entries in the bay with MSMA and permanent flood. Notes on the presence or absence of symptoms on late tillers were documented from the bay with MSMA and intermittent flooding.

Results and Discussion

Differences were observed between the three bays tested for straighthead. The bay with MSMA and permanent flood showed 7 VS, 3 S, 14 MR, and 4 R as rated in reference to the reactions of the control varieties. Two entries did not emerge and were missing (Table 1; Fig. 1). From the bay that received MSMA and was treated with intermittent flushing, only those that rated VS showed 2 to 5 of their late tillers with mild symptoms of straighthead. Among the entries that received no MSMA and were kept under permanent flood, none showed any symptoms of straighthead. All heads of each entry had matured normally and appeared healthy.

Such information regarding the response of commercial rice varieties to straighthead is important to producers as they make early decisions on varietal selection, plan usage of water resources, and anticipate costs that may be incurred by following the “drain and dry strategy." The experiment will be repeated in 2020 with more advanced breeding lines included.

Practical Applications

Using the “drain and dry” strategy to manage straighthead is difficult in fields that are big, where water is limited, and pump capacity is unable to re-flood the field in a 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 alternative strategy to prevent significant losses that may have occurred due to this disorder.

Acknowledgments

The authors appreciate the funding and support from the Arkansas rice producers through monies administered by the Arkansas Rice Research and Promotion Board, and the University of Arkansas System Division of Agriculture. Our appreciation goes to our program crew, Christy Kelsey and Temesgen Mulaw in different ways and special thanks goes to Scott Belmar who helped with this experiment in seed set up and planting.

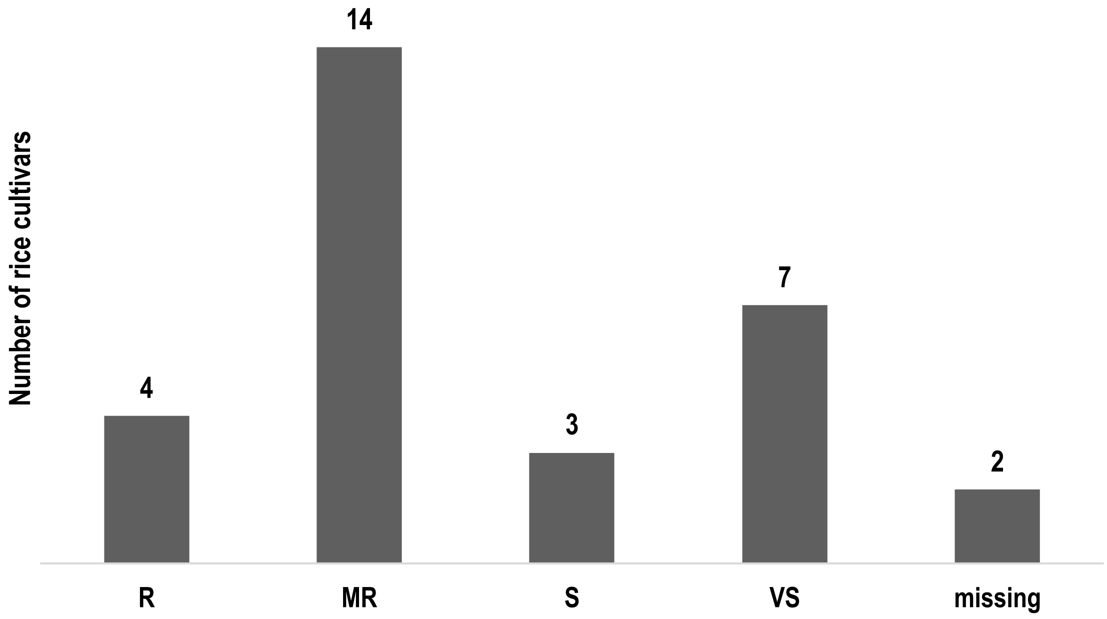

Fig. 1. Reactions of rice cultivars to straighthead induced by monosodium methanearsonate (MSMA). R = resistant; MR = moderately resistant; S = susceptible; VS = very susceptible; missing = failed to survive.

Table 1. Reactions of rice cultivars to monosodium methanearsonate to evaluate tolerance to straighthead.

Entry #	Cultivar	Previous Reaction	2019 Reaction 0–9 scale	Susceptibility Level
1	ARoma 17	-	9	VS
2	CL111	S[b]	9	VS
3	CL153	--	9	VS
4	CL163	--	7	S
5	CL172	--	1	R
6	CL272	--	7	S
7	Della-2	--	9	VS
8	Diamond	--	4	MR
9	Jazzman-2	--	Missing	
10	Jupiter	S	1	R
11	LaKast	MS	4	MR
12	Mermentau	VS	9	VS
13	PVL01	-	4	MR
14	Rex	S	8	S
15	Roy J	S	4	MR
16	RT Gemini 214 CL	-	4	MR
17	RT XP113	-	4	MR
18	RT XP753	-	4	MR
19	Titan	MS	5	MR
20	Wells	-	9	VS
21	RU1901133	-	1	R
22	RU1801101	-	Missing	
23	RU1801169	MS	4	MR
24	RU1701185	--	1	R
25	RU1701121	-	4	MR
26	CLL15	S	5	MR
27	CLM04	-	4	MR
28	RU1701081	-	5	MR
29	RU1701084	-	4	MR
30	RU1701087	-	9	VS
C1[a]	CL151	VS	9	VS
C2	Cocodrie	VS	9	VS
C3	Francis	MR	5	MR
C4	XL745	R	1	R
C5	Taggart	R	1	R

[a] C1, C2, C3, C4 and C5 were known cultivars used as control.

[b] S (susceptible), VS (very susceptible), MS (moderately susceptible), R (resistant), and MR (moderately resistant); Missing = failed to survive.

Evaluation of Fungicide Application and Coverage to Suppress Rice Diseases Using Sheath Blight as a Model

Y. Wamishe,[1] J. Hardke,[2] T. Gebremariam,[1] S.B. Belmar,[1] C.D. Kelsey,[1] and T. Mulaw[1]

Abstract

Sheath blight caused by *Rhizoctonia solani* AG1-1A is the most prevalent disease in rice, causing up to 15% grain yield loss in Arkansas. Nearly 57% of rice fields in Arkansas receive at least one fungicide application every year and most of these fungicides are intended to manage sheath blight. In some commercial fields, minimal amounts of water are used for foliar fungicide application; hence, the disease may not be suppressed enough to avoid economic yield loss. A field test was conducted in 2019 to evaluate three volumes of water for fungicide application: 3, 10 and 20 gallons per acre (GPA) rate using Amistar Top and Quilt Xcel. A susceptible variety, CL163, was artificially inoculated with the *Rhizoctonia* sp. at panicle initiation and the fungicides were applied seven days after inoculation using a Mud Master sprayer. Each treatment had four replications. Vertical and horizontal disease ratings were taken three times at 21 and 28 days after application (DAA) and a week before harvest. Disease indices were calculated to combine the vertical and horizontal ratings. Disease index, grain yield, test weight, total and head yield data were recorded. No significant differences in efficacy were observed between Amistar Top and Quilt Xcel for sheath blight suppression. However, there were differences between unsprayed and sprayed plots in sheath blight progress and grain yield. Plots that received the fungicides with carrier volume of 3 GPA were not significantly different from the unsprayed plots, while plots sprayed with carrier volumes of 10 or 20 GPA water were significantly different in disease and yield from unsprayed plots and those that received the fungicides with a carrier volume of 3 GPA water. Test weight, total and head yield were not significantly different among treatments. This study supports the importance of adequate coverage through higher GPA to increase fungicide efficacy.

Introduction

Rhizoctonia solani AG1-1A is a soilborne fungus that causes sheath blight in rice which accounts for yield losses of 5 to 30 bu./ac (Wamishe et al., 2018) in Arkansas. The pathogen has a wide host range including soybean, bean, sorghum, corn, sugarcane, turfgrass, and weed hosts such as barnyard grass, crabgrass, and broadleaf signal grass among others. In rice, sheath blight is one of the major diseases in Arkansas where nearly 50% of the U.S. rice is produced. The fungus survives in soil as mycelia but mostly as mycelial mass known as "sclerotia." The monocyclic infection in flooded rice starts at the waterline. Once infection starts, the disease progresses upward in the plant canopy. The pathogen spreads laterally and a polycyclic infection continues to neighboring plants through leaf-to-leaf contact under conditions that favor the fungus's survival and reproduction.

Nearly 57% of rice fields (Hardke, 2018) in Arkansas receive at least one fungicide application every year and most of the fungicides are intended to manage sheath blight in susceptible or moderately susceptible rice varieties. However, in some fields, rice diseases including sheath blast, kernel and false smut may not be suppressed by the fungicides as intended. One major reason is thought to be that the rice canopy is receiving less chemical coverage due to an inadequate volume of water used as a carrier to deliver the fungicides. Therefore, the objective of the experiment was to test two commercially available fungicides with three different carrier volumes of water to determine suppression of sheath blight as a model rice disease. Sheath blight was selected as a model rice disease because the pathogen can easily be applied to plants and disease development in field plots is more consistent than other rice diseases.

Procedures

A field experiment was established in 2019 at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC) near Stuttgart, Arkansas. To test coverage of fungicides for sheath blight management, a susceptible long-grain variety, CL163, was drill-seeded on 23 April with an 8-row planter at 83 lb seed/acre in 30-ft by 5-ft strip plots. The trial was a randomized complete block design with four replications with two factors: fungicide and carrier water volume.

Plots received urea a day prior to permanent flood, at 105 lb N/acre on 30 May as well as a mid-season application of 45 lb N/acre. Rice plants were then inoculated on 25 June with corn and rice-based *R. solani* AG1-1A inoculum between panicle initiation and panicle differentiation. A 16-fl oz cup was used twice to measure out about 200 g of the inoculum. The inoculum was hand-broadcasted over each plot followed by a gentle sweep using a PVC pipe approximately 1.3 in. OD (outside diam.) to knock

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[1] Associate Professor, Program Associate, Program Technician, Program Technician, Program Technician, respectively, Department of Plant Pathology, Rice Research and Extension Center, Stuttgart.

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

down the inoculum from foliage into the flood water so the infection could start from the waterline. Amistar Top and Quilt Xcel were sprayed on 2 July at 15 oz/acre and 21 oz/acre, respectively using three carrier volumes of water, 3, 10 and 20 gallons per acre (GPA) rate. MudMaster™ model MM2013 was used to deliver the fungicides using all three volumes of water with three sets of different nozzles. Disease progress data up to the canopy were collected three times during the season i.e, 21 and 28 days after the fungicide application (DAA) and 7 days prior 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. Plots were harvested on 9 September with a Wintersteiger classic plot combine. Disease index was calculated by multiplying the vertical disease progress with the horizontal progress. Disease, yield, test weight, total and head yield data were analyzed statistically using PROC GLM procedure in SAS 9.4 (SAS Institute, Inc., Cary N.C.).

Results and Discussion

The analysis showed no significant difference in efficacy between Amistar Top and Quilt Xcel in the degree of sheath blight suppression (Fig. 1). Both fungicides had nearly similar activity on *Rhizoctonia solani* AG1-1A. This result was expected since the rates used for each fungicide provided an Azoxystrobin equivalent of 12 oz/acre rate of Quadris. There were differences between plots that received fungicides and those that were not sprayed. Sheath blight in unsprayed plots showed progression throughout the season. There was a significant difference in disease level among plots that received fungicides with different carrier volumes of water. The difference in disease levels between the sprayed plots with 3 GPA was not significantly different from the unsprayed plots (Fig. 1).

There were also differences in grain yield between the sprayed and unsprayed plots. Again, the differences in grain yield were among the plots that received fungicides with different carrier volumes of water. No significant difference in grain yield was observed between the sprayed plots using 3 GPA and the unsprayed plots (Fig. 2). However, those plots that received fungicides using 10 GPA and 20 GPA had significantly higher yield compared to the unsprayed plots and the sprayed plots with 3 GPA. Test weight, total and head yield were not significantly different. Although this report presents a single year of data, the study supports the need and prominence of adequate coverage to increase fungicide efficacy. The test will be repeated in the 2020 crop season.

Practical Applications

There are times that fungicides may be delivered but diseases may not be suppressed as intended. Such situations incur application and grain yield loss from the 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. Fungicides protect the crop better in well managed fields, underlining the importance of using at least 10 GPA to disperse the chemical for good canopy 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.

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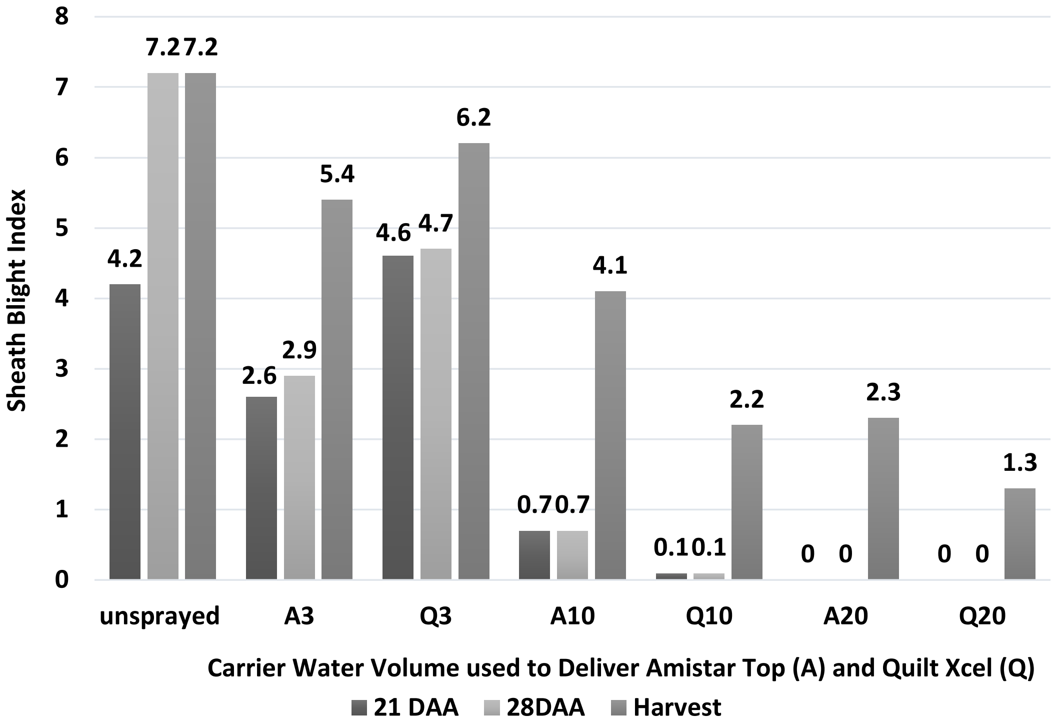

Fig. 1. Sheath blight disease indices as collected 21 and 28 days after application (DAA) and a week before harvest using Amistar Top (A) at 15 oz/acre and Quilt Xcel (Q) at 21 oz/acre using carrier volumes of 3, 10, and 20 gallons per acre (GPA) water in artificially inoculated susceptible rice variety, CL163 in 2019. LSD 0.05 = 1.32, 1.01, 1.97 for 21, 28, and harvest, respectively. 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.

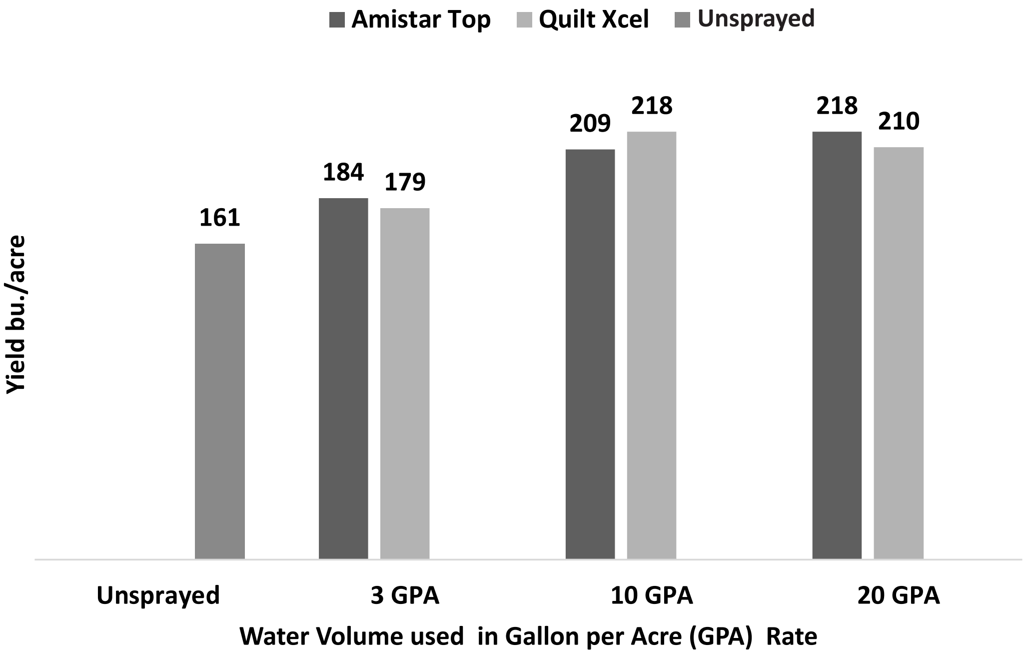

Fig. 2. Mean grain yield of plots that received Amistar Top at 15 oz/acre and Quilt Xcel at 21 oz/acre with 3, 10, and 20 gallons per acre (GPA) water in artificially inoculated with *Rhizoctonia solani* AG-1A susceptible rice variety, CL163 in 2019. LSD (0.05) = 23.002.

Insecticide Seed Treatment Combinations for Control of Rice Water Weevil

B.C. Thrash,[1] G.M. Lorenz,[1] N.R. Bateman,[2] N.M Taillon,[1] S.G. Felts,[2] W.A. Plummer,[1] W.J. Plummer,[1]
J.K. McPherson,[1] T.L. Clayton,[3] C.A. Floyd,[4] and C. Rice[4]

Abstract

Grape colaspis and rice water weevil are serious insect pests of rice in Arkansas and are primarily controlled with insecticide seed treatments. Neonicotinoids seed treatments generally provide good control of both; however, their performance can fall short on rice water weevil when rice is planted very early and permanent flood will be established greater than 30 days after planting. Diamide seed treatments can provide season long control of rice water weevil but offer essentially no protection from grape colaspis. The results of these tests indicate that insecticide seed treatment combinations provide greater control of rice water weevil and improve yields in a delayed flood scenario, when compared to a single product seed treatment.

Introduction

Grape colaspis (*Colaspis brunnea*, GC) and rice water weevil (*Lissorhoptrus oryzophilus*, RWW) are the two most important soil pests of rice in Arkansas. Grape colaspis larvae damage rice plant roots at the seedling stage causing the rice plants to die and resulting in thin plant stands. Once a permanent flood is established, RWW migrate into the field and are attracted to areas with the thin stands caused by GC feeding. The RWW adults feed on the rice leaves causing white, linear scars, but these scars do not contribute to yield loss. The RWW larvae feed on the outside of the plant and make their way into the root system. While in the soil, the larvae feed on the plant roots, reducing nutrient translocation and ultimately reducing yield (Lorenz et al., 2018).

Neonicotinoid (CruiserMaxx® and NipsIt Inside®) seed treatments are the primary method of control for grape colaspis, however these treatments can only protect rice seedlings for approximately 30 days after planting. Many rice producers are moving toward earlier planting dates, which means the length of time between planting and establishment of permanent flood is increasing. If the time between planting and permanent flood is greater than 30 days, neonicotinoid seed treatments cannot protect rice seedlings from rice water weevil. Diamide (Dermacor® X 100 and Fortenza®) seed treatments are highly effective on RWW larvae and last in the plant much longer than neonicotinoid seed treatments, although they are not as effective in controlling grape colaspis. Combinations of neonicotinoid and diamide insecticide seed treatments were evaluated in order to determine whether they can improve control of rice water weevil over single products in these situations.

Procedures

Studies were conducted in 2019 at the University of Arkansas System Division of Agriculture's Pine Tree Research Station (PTRS) near Colt, Arkansas and the RiceTec Research Station (RTRS) near Harrisburg, Arkansas. RiceTec CLXL745 was planted at each location. Plots were 8 rows (7.5-in. spacing) wide and 16.5 ft in length arranged in a randomized complete block design with four replications. Trials were planted on 30 April (RTRS) and 16 May (PTRS). Treatments are listed in Table 1. The RWW larvae were evaluated by taking 3 core samples per plot with a 4-inch core sampler 21 days after permanent flood was established. These samples were then washed in a number 40 mesh sieve and examined in a saltwater solution at the Lonoke County Extension Center. Plots were harvested and yield data were collected. Data were processed using Agriculture Research Manager Version 10, analysis of variance, and Duncan's New Multiple Range Test ($P = 0.10$) to separate means.

Results and Discussion

All treatments reduced RWW compared to the untreated check (UTC) at PTRS (Fig. 1). Plots treated with NipsIt Suite 2.9 oz and CruiserMaxx 7 oz provided less control of RWW compared to Fortenza 3.47 oz, Dermacor at 5 oz, and CruiserMaxx 7 oz + Fortenza 3.47 oz. All treatments showed an increase in yield compared to the UTC (Fig. 2). CruiserMaxx 7 oz + Dermacor 5 oz had greater yield than plots treated with NipsIt Suite 2.9 oz.

All treatments reduced RWW populations numerically compared to the UTC at RTRS (Fig. 3). Plots treated with CruiserMaxx 7 oz + NipsIt 2.9 oz, NipsIt Suite 2.9 oz + Fortenza 3.47 oz, and Dermacor 5 oz provided greater control for RWW than CruiserMaxx 7 oz and NipsIt Suite 2.9 oz. A general trend was observed that the combinations of insecticide seed treatments yielded higher than the UTC (Figs. 4 and 5).

Combinations of diamide and neonicotinoid insecticide seed treatments provided season-long control of RWW. Higher yields were observed for combinations of seed treatments compared to any single insecticide seed treatment product.

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[1] Assistant Professor/Extension Entomologist, Distinguished Professor/Extension Entomologist, Program Associate, Program Associate, Program Associate, and Program Associate, respectively, Department of Entomology and Plant Pathology, Lonoke.

[2] Assistant Professor/Extension Entomologist and Program Associate, respectively, Department of Entomology and Plant Pathology, Stuttgart.

[3] Program Associate, Department of Crop, Soil, and Environmental Sciences, Stuttgart.

[4] Graduate Assistant and Graduate Assistant, respectively, Department of Entomology and Plant Pathology, Fayetteville.

Practical Applications

This data suggests growers should consider using an insecticide seed treatment combination in areas where GC and RWW are a problem and the time between planting and permanent flood establishment will be over 30 days.

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.

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Table 1. List of treatments and rates.

Treatment	Rates	Insecticide Class
Fungicide only untreated check (UTC)		
NipsIt Suite	2.9 oz/cwt	Neonicotinoid
CruiserMaxx	7 oz/cwt	Neonicotinoid
Dermacor	5 oz/cwt	Diamide
Fortenza	3.47 oz/cwt	Diamide
NipsIt Suite + Dermacor	2.9 oz/cwt + 5 oz/cwt	Neonicotinoid + Diamide
NipsIt Suite + Fortenza	2.9 oz/cwt + 3.47 oz/cwt	Neonicotinoid + Diamide
CruiserMaxx + Dermacor	7 oz/cwt + 5 oz/cwt	Neonicotinoid + Diamide
CruiserMaxx + Fortenza	7 oz/cwt + 3.47 oz/cwt	Neonicotinoid + Diamide
CruiserMaxx + NipsIt Suite	7 oz/cwt + 2.9 oz/cwt	Neonicotinoid + Neonicotinoid

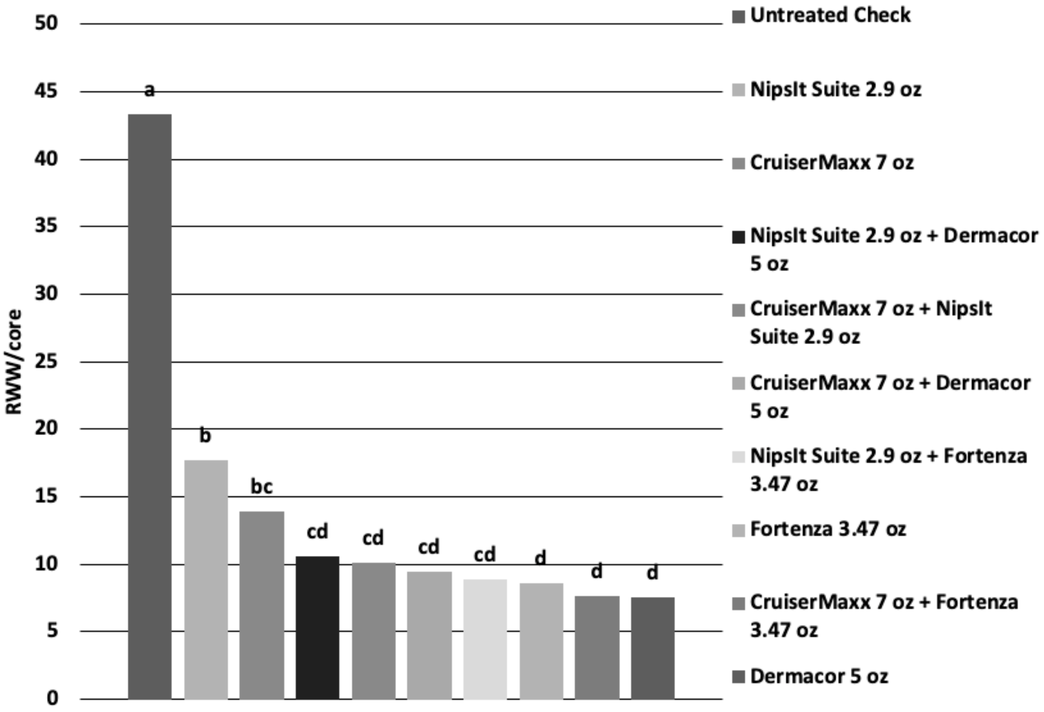

Fig. 1. Average number of rice water weevil (RWW) per core sample at the University of Arkansas System Division of Agriculture's Pine Tree Research Station. Means followed by the same letter are not significantly different from one another at an alpha level of 0.1.

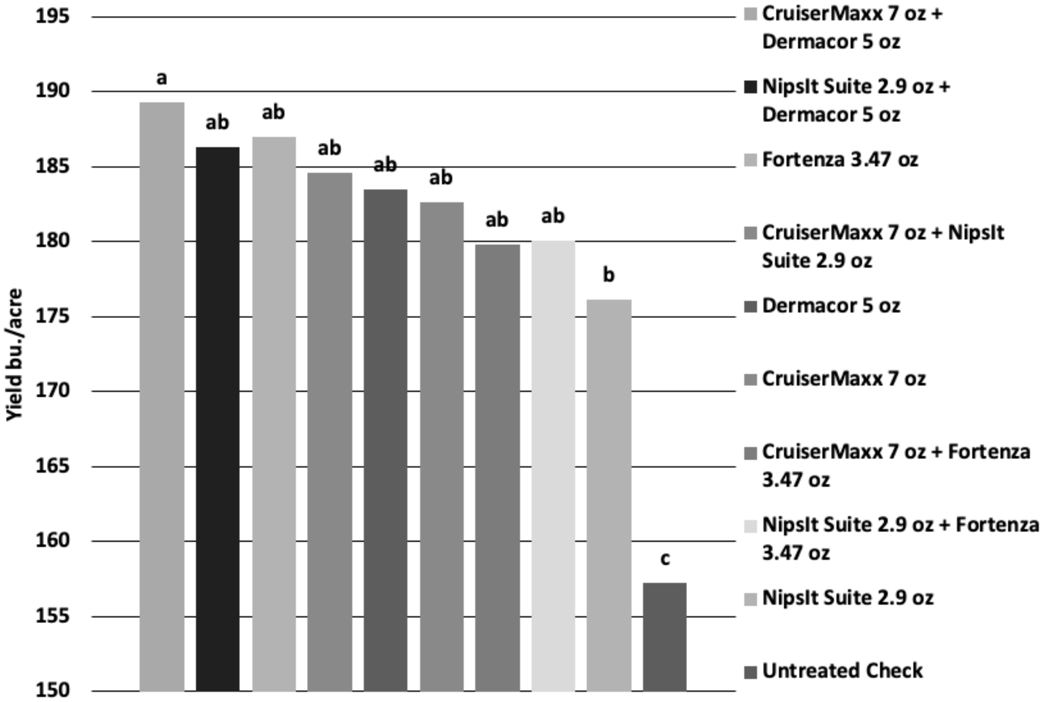

Fig. 2. Yields at the University of Arkansas System Division of Agriculture's Pine Tree Research Station in bushels per acre. Means followed by the same letter are not significantly different from one another at an alpha level of 0.1.

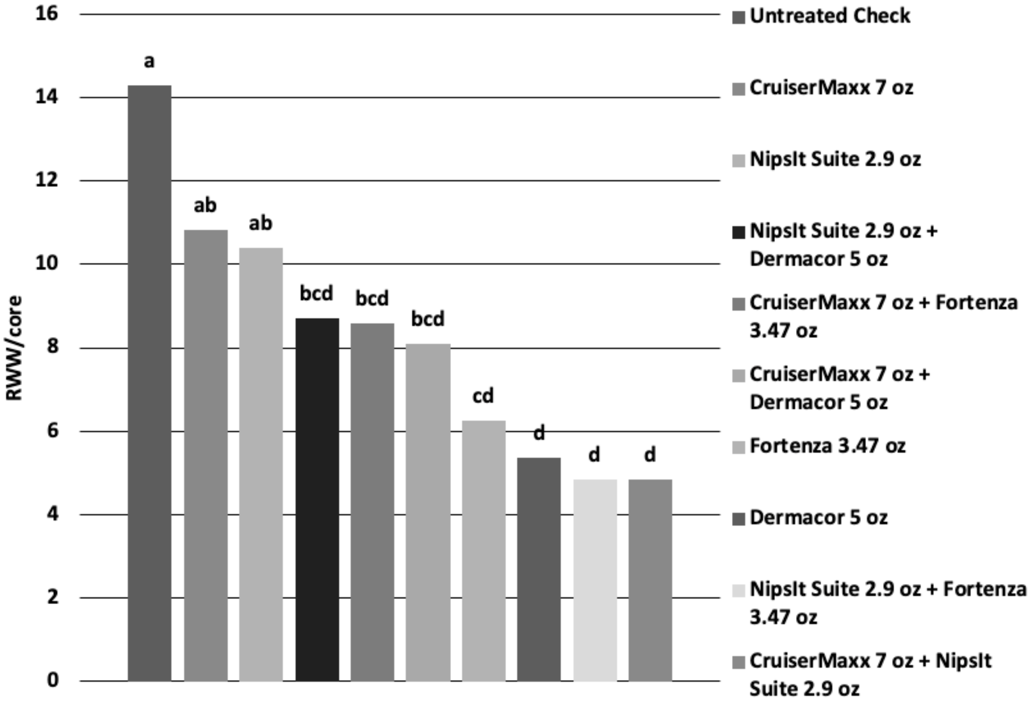

Fig. 3. Average number of rice water weevil (RWW) per core sample at the RiceTec Research Station (RTRS) near Harrisburg, Arkansas. Means followed by the same letter are not significantly different from one another at an alpha level of 0.1.

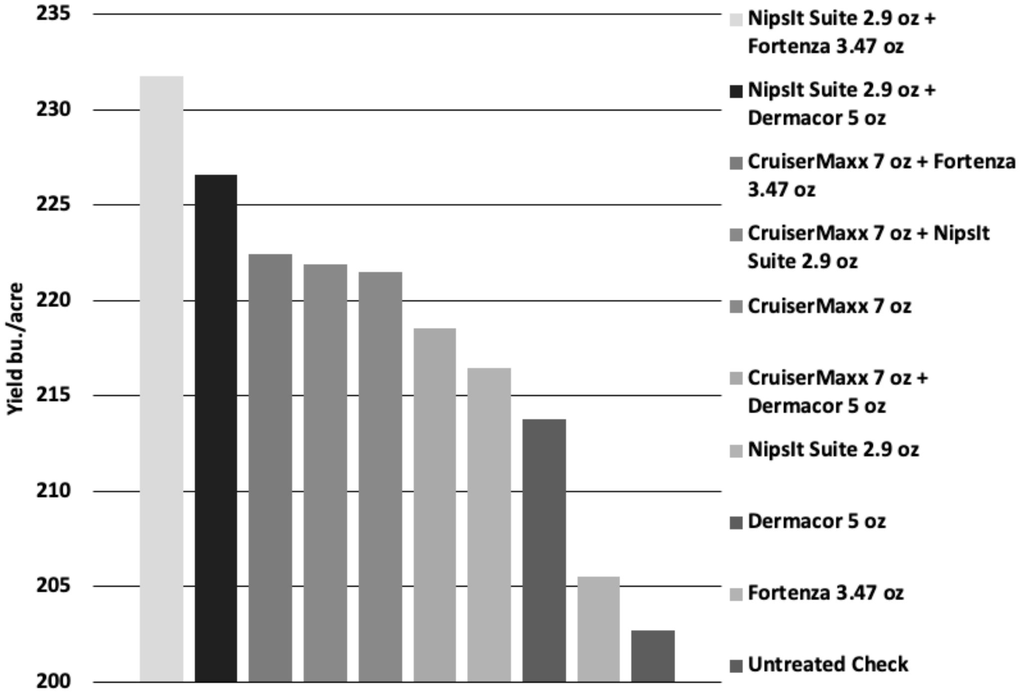

Fig. 4. Yields at the RiceTec Research Station (RTRS) near Harrisburg, Arkansas in bushels per acre.

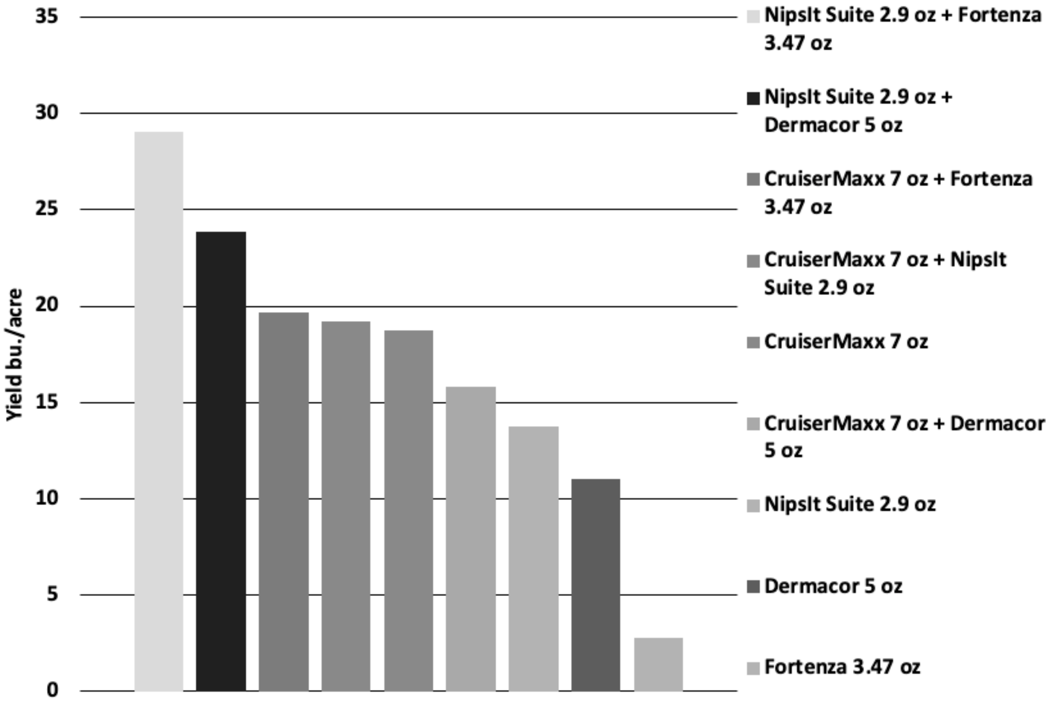

Fig. 5. Yield above the untreated check for the RiceTec Research Station (RTRS) near Harrisburg, Arkansas and the University of Arkansas System Division of Agriculture's Pine Tree Research Station combined.

Reevaluation of the Current Rice Stink Bug Threshold for Arkansas

*N.R. Bateman,[1] G.M. Lorenz,[2] B.C. Thrash,[2] N.M Taillon,[2] S.G. Felts,[1] W.A. Plummer,[2] W.J. Plummer,[2]
J.K. McPherson,[2] T.L. Clayton,[3] C.A. Floyd,[4] and C. Rice[4]*

Abstract

Rice stink bug is the major pest of heading rice in the mid-South. Thresholds for rice stink bug around the mid-South have lowered in recent years compared to the threshold in Arkansas. The current threshold in Arkansas for rice stink bug is 5 rice stink bugs per 10 sweeps during the first two weeks of heading, and 10 per 10 sweeps during the second two weeks of heading. With thresholds changing for states bordering Arkansas, it is important to reevaluate the current threshold so that growers can stay profitable. A study was conducted on grower fields in 2019 to evaluate the standard threshold compared to an untreated or 10 all season threshold. Our current threshold was the only treatment to yield higher than the untreated. No differences were observed among the standard threshold and the 10 all season for milling yields or quality ratings, but in most cases these treatments were better than the untreated.

Introduction

The rice stink bug, *Oebalus pugnax*, is the number one pest of heading rice in the southern United States (Webb, 1920). The rice stink bug feeds on grasses and grass crops during the heading growth stage. When feeding happens during the flowering and milk growth stages, direct yield loss can occur. During the ripening phase (soft dough and hard dough), rice stink bugs can cause broken, shrunken, and discolored kernels (Swanson and Newsom, 1962). This quality loss is referred to as pecky rice and growers receive a price reduction when peck levels are at 2.5% or greater.

Rice stink bug thresholds in the southern U.S. vary greatly from one state to another. Currently in Arkansas, the threshold changes based on rice growth stage. In the early season, or the first two weeks after the rice crop is at 75% heading, the threshold is 5 rice stink bugs per 10 sweeps. The threshold then increases during the third and fourth weeks of heading to 10 rice stink bugs per 10 sweeps (Lorenz et al., 2018). Recently, rice-producing states surrounding Arkansas have changed their thresholds and it is imperative to reevaluate the current threshold to keep growers profitable.

Procedures

Experiments to evaluate multiple rice stink bug thresholds experiments were conducted in 2019 at 4 locations in Arkansas: Almyra, Altheimer, Stuttgart, and Ulm. These experiments were conducted on grower fields, therefore agronomic practices and cultivar varied between locations. At each location, 3 thresholds were compared: an untreated check (never sprayed for rice stink bug), the current threshold of 5 rice stink bugs per 10 sweeps during the first two weeks of heading and 10 rice stink bugs per 10 sweeps during the second two weeks of heading, and a 10 rice stink bugs per 10 sweeps all season. Each plot was sampled weekly, from the flowering growth stage through 60–70% hard dough, by conducting 2 sets of 10 sweeps per plot. When a threshold was met or exceeded, a foliar application of 3.65 oz/ac of Lambda-Cy (Lambda cyhalothrin) was made using a backpack sprayer equipped with TeeJet TX-6 hollow cone nozzles, calibrated to 10 gal/ac. Plot size was 20 ft by 50 ft, and plots were arranged as a randomized complete block with four replications at each location. All data were analyzed using PROC GLIMMIX SAS v 9.4 (SAS Institute, Inc., Cary N.C.).

Results and Discussion

A significant yield increase was observed for the standard threshold treatment compared to the untreated. The 10 all season threshold did not yield differently from the untreated or the standard threshold. Total rice yields and head rice yields were increased with the standard threshold and the 10 all season threshold compared to the untreated, however no differences were observed between the standard threshold or the 10 all season threshold (Table 1).

No differences were observed at either the Almyra or Stuttgart locations for rice stink bug peck or total peck. At the Altheimer and Ulm locations, both the standard threshold and 10 all season threshold decreased rice stink bug peck and total peck compared to the untreated. Only the Altheimer and Ulm locations exceeded 2.5% peck, which is the point at which growers would get docked when selling their grain (Table 2).

Practical Applications

Recently, thresholds for rice stink bug have changed dramatically around the rice-producing states. This data suggests that

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[1] Assistant Professor/Extension Entomologist and Program Associate, respectively, Department of Entomology and Plant Pathology, Stuttgart.

[2] Professor/Extension Entomologist, Assistant Professor/Extension Entomologist, Program Associate, Program Associate, Program Associate, and Program Associate, respectively, Department of Entomology and Plant Pathology, Lonoke.

[3] Program Associate, Department of Crop, Soil, and Environmental Sciences, Stuttgart.

[4] Graduate Assistant and Graduate Assistant, respectively, Department of Entomology and Plant Pathology, Fayetteville.

the current threshold for rice stink bug is adequate for keeping growers profitable. No differences were observed between the standard threshold and the 10 all season threshold for milling yields or quality ratings; however the standard threshold was the only threshold to out-yield the untreated. Currently, there is no need to adjust the threshold, although it will continue to be reevaluated to protect growers from losses associated with rice stink bug.

Acknowledgments

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

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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

Webb, J.L. 1920. How insects affect the rice crop. U.S. Department of Agriculture Farmers Bulletin:1086.

Table 1. Yield and milling yields for multiple rice stink bug thresholds.

Threshold	bu./ac	%TR[†]	%HR[‡]
Untreated	163.1(4.1) b[§]	71.2 (0.3) b	57.0 (1.1) b
Standard	177.0 (3.3) a	72.3 (0.4) a	59.2 (1.6) a
10 All Season	172.6 (7.2) ab	72.0 (0.4) a	58.7 (1.5) a
***P*-value**	0.04	<0.01	0.01

[†] Percent total rice.

[‡] Percent head rice.

[§] Means followed by the same letter are not significantly different at $\alpha = 0.05$.

Table 2. Rice stink bug and total peck analysis for multiple rice stink bug thresholds at 4 locations in Arkansas, 2019.

	Location							
	Almyra		Altheimer		Stuttgart		Ulm	
Threshold	RSB[†]	Total	RSB	Total	RSB	Total	Total	Total
Untreated	1.8 (0.2) a[‡]	2.0 (0.2) a	2.4 (0.2) a	2.7 (0.2) a	2.0 (0.2) a	2.1 (0.3) a	2.4 (0.2) a	2.7 (0.2) a
Standard	1.6 (0.2) a	1.4 (0.2) a	1.5 (0.1) b	1.7 (0.3) b	1.3 (0.2) a	1.5 (0.4) a	1.4 (0.2) b	1.7 (0.3) b
10 All Season	1.3 (0.1) a	1.9 (0.2) a	1.4 (0.2) b	1.8 (0.1) b	1.6 (0.3) a	1.8 (0.3) a	1.5 (0.1) b	1.8 (0.1) b
***P*-value**	0.2	0.2	<0.01	<0.01	0.07	0.17	<0.01	<0.01

[†] Rice stink bug peck.

[‡] Means followed by the same letter are not significantly different at $\alpha = 0.05$.

Large Block Comparisons of *Dinotefuran* and *Lambda-Cyhalothrin* for Control of Rice Stink Bug

*N.R. Bateman,[1] G.M. Lorenz,[2] B.C. Thrash,[2] N.M Taillon,[2] S.G. Felts,[1] W.A. Plummer,[2] W.J. Plummer,[2]
J.K. McPherson,[2] T.L. Clayton,[3] C.A. Floyd,[4] and C. Rice[4]*

Abstract

Rice stink bug is the number one pest of heading rice, causing both yield and quality loss. There are few products available to growers to control rice stink bug. Limited residual control has been observed for all insecticides labeled for control of rice stink bug. Large block comparisons were conducted at three locations in 2019 to compare *lambda-cyhalothrin* and *dinotefuron* for efficacy and residual control of rice stink bug. No differences were observed between the two products at any location or sample date.

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. Limited insecticide options are currently available for RSB control (Lorenz et al., 2018). *Lambda-cyhalothrin* (Warrior II and Generics), a pyrethroid, is the current standard for RSB control due to it being highly efficacious and its economical price of $2/ac. However, these products provide little to no residual control for RSB. Growers do have another option in *dinotefuran* (Tenchu), but it is considerably more expensive than Lambda at $12/ac. The objective of this study was to compare the efficacy and residual control of Lambda and Tenchu for control of RSB.

Procedures

Large block comparisons of Lambda and Tenchu were conducted at three locations, Arkansas County, Jefferson County, and Lincoln County, in 2019. One field in each county was split, with Lambda applied to one-half and Tenchu to the other half. Fields were selected that were at or exceeding the RSB threshold. Plot size was a minimum of 25 acres for both products. Applications were made using an airplane at 3 gal/ac. Warrior II was used to represent lambda at 1.8 oz/ac, and Tenchu was applied at 7.5 oz/ac. Crop oil was added to both products at the labeled rate. The RSB densities were estimated using a sweep net at 3, 7, 10, 14, and 17 days after treatment (DAT), by conducting 10 sets of 10 sweeps per plot. Sweep net samples were taken throughout the application area. If either or both treated blocks exceeded threshold after the initial application, it was retreated. Sampling was conducted until both plots reached 60% hard dough.

Results and Discussion

Arkansas County

Densities of RSB were between 2 and 3 times higher than threshold prior to application. No differences for RSB densities were observed at any sampling date between Lambda and Tenchu. Both products were able to keep RSB densities below threshold out to 17 DAT.

Jefferson County

Pre-spray densities of RSB were slightly above threshold for both blocks. After application, RSB densities were reduced below threshold out to 15 DAT. No differences were observed between treatments at any sampling date (Fig. 1).

Lincoln County

Prior to the application being made, RSB densities were 5 times higher than the threshold. At 4 DAT and 6 DAT, RSB densities exceeded threshold for Lambda and Tenchu. Plots were retreated after the 6 DAT sampling. At 3, 6, and 10 DAT-B, both products reduced RSB densities lower than the threshold, but no difference was observed between the treatments at any sampling date (Fig. 2).

Overall no differences were observed at any location between Lambda and Tenchu. Both products provided adequate knockdown, although neither product provided residual control when high populations of RSB were present (Fig. 3).

Practical Applications

Currently limited products are available for control of RSB. In these studies, we observed no difference in efficacy and residual control between Lambda and Tenchu. The largest

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[1] Assistant Professor/Extension Entomologist and Program Associate, respectively, Department of Entomology and Plant Pathology, Stuttgart.

[2] Professor/Extension Entomologist, Assistant Professor/Extension Entomologist, Program Associate, Program Associate, Program Associate, and Program Associate, respectively, Department of Entomology and Plant Pathology, Lonoke.

[3] Program Associate, Department of Crop, Soil, and Environmental Sciences, Stuttgart.

[4] Graduate Assistant and Graduate Assistant, respectively, Department of Entomology and Plant Pathology, Fayetteville.

difference between these products is the cost. Lambda costs approximately $2/ac whereas Tenchu is $12/ac. With these prices, growers can spray Lambda twice for the cost of one application of Tenchu when application fees are added in. Growers can stay more profitable and achieve the same results for RSB control with the use of Lambda compared to Tenchu.

Acknowledgments

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

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Lorenz, G., N. Bateman, J. Hardke, 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.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.

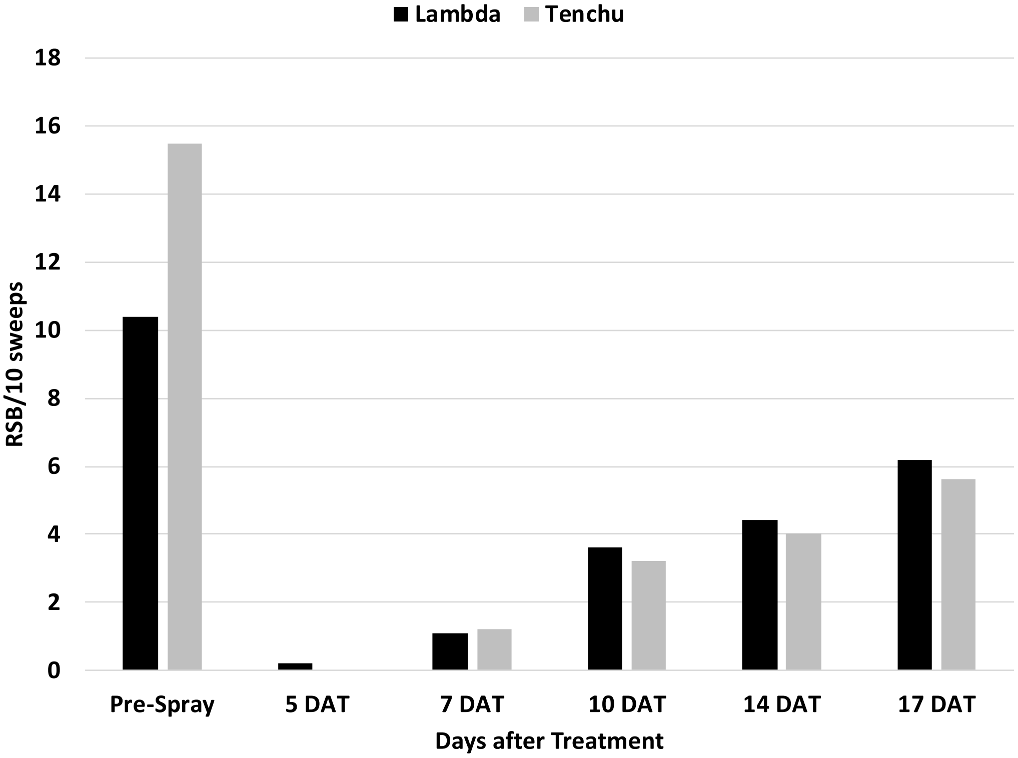

Fig. 1. Large block comparison of Lambda and Tenchu for rice stink bug (RSB) control in Arkansas County.

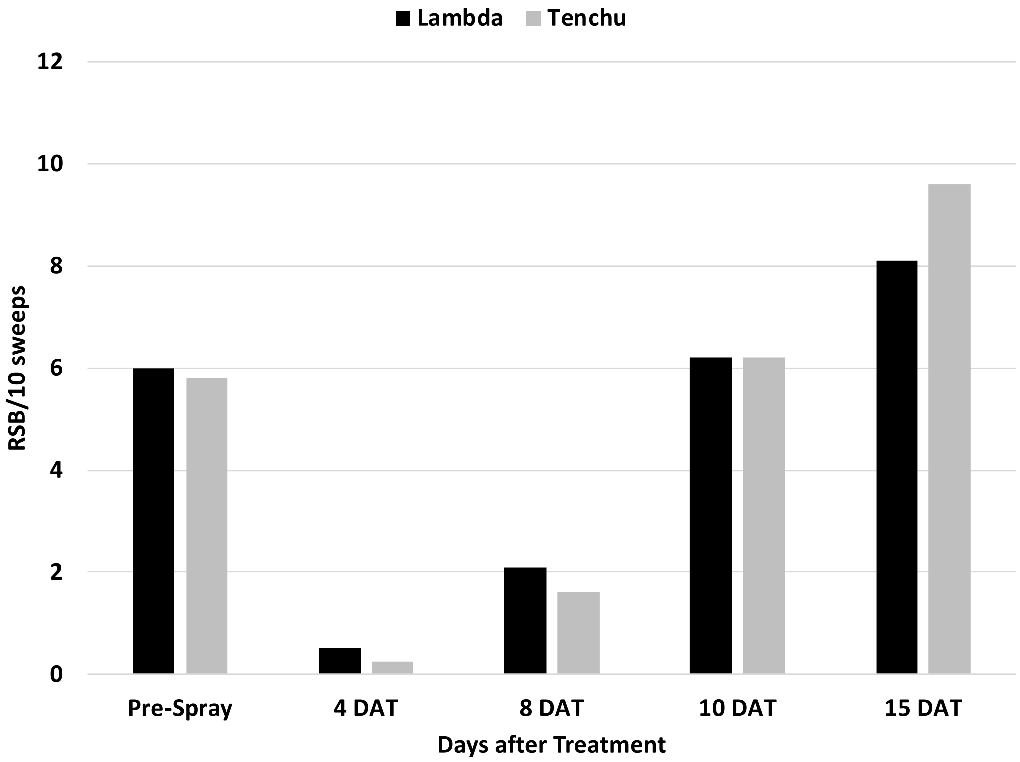

Fig. 2. Large block comparison of Lambda and Tenchu for rice stink bug (RSB) control in Jefferson County.

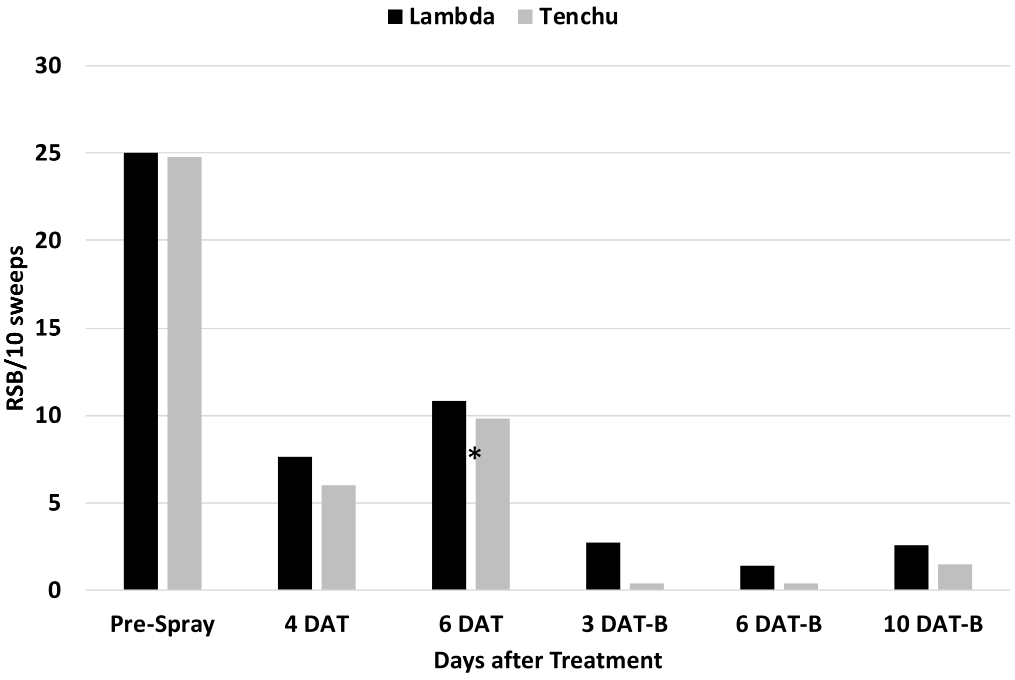

Fig. 3. Large block comparison of Lambda and Tenchu for rice stink bug (RSB) control in Lincoln County.

Acephate Degradation in Rice

N.R. Bateman,[1] G.M. Lorenz,[2] B.C. Thrash,[2] N.M Taillon,[2] S.G. Felts,[1] W.A. Plummer,[2]
W.J. Plummer,[2] J.K. McPherson,[2] T.L. Clayton,[3] C.A. Floyd,[4] and C. Rice[4]

Abstract

Studies were conducted in 2018 to determine the rate of degradation of acephate and its metabolite, methamidophos, from multiple foliar timings in rice. Acephate was applied at 60% hard dough, 1 day prior to harvest, and 7 days prior to harvest. Samples from 7 days after harvest and 30 days after were sent to the United States Department of Agriculture laboratory in Gastonia, N.C. to be analyzed for detections of acephate and methamidophos. High levels of both acephate and methamidophos were observed for both sample dates and all foliar timings.

Introduction

Arkansas produces approximately 50% of the total rice in the U.S. with an average of 1.3 million acres on a yearly basis (USDA-NASS, 2020). Almost all the rice produced in Arkansas is exported to foreign countries. Recently, multiple barges have been turned away at ports in South America due to low levels of acephate being detected on the grain. Acephate is not labeled for use in rice, and tolerance on the grain is very low at, 0.1 parts per million or 10 parts per billion. Acephate and its metabolite methamidophos, has been documented to break down during handling and washing of rough rice, but it can still be detected in most cases (Kong et al., 2012). The objective of this study was to determine the rate of acephate and methamidophos degradation for different foliar timings in rice.

Procedures

An experiment was conducted in 2018 at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center, near Stuttgart Arkansas, to determine how quickly acephate degrades in rice. Diamond rice was seeded at 70 lb/ac on 16 April. Plot size was 8 rows (7.5-in spacing) by 16.5 ft. Orthene 97 was applied at 1 lb/ac with a backpack sprayer calibrated to 10 gal/ac at 2.5 MPH with TeeJet TX-6 hollow cone nozzles. Applications were made at three timings, 60% hard dough (60% HD), 7 days prior to harvest, and 1 day prior to harvest (7 PHI and 1 PHI respectively). The 60% HD application was made 19 days prior to harvest. Plots were arranged in a randomized complete block design with 4 replications. Harvest was conducted using a plot combine and a 5-lb grain sample was collected from each plot. Grain samples were placed in a drier and dried until 12% moisture was achieved. After drying, subsamples of grain were collected and sent to the United States Department of Agriculture, Agricultural Marketing Service–Science and Technology Laboratory Approval and Testing Division of the National Science Laboratories' Gastonia Lab in Gastonia N.C. for analysis of acephate or methamidophos presence. The remaining grain samples were kept in cloth bags in a dark closet with a constant temperature of 70 ºF. After 30 days of storage, another subsample of grain was collect and shipped to the same lab for processing. The detection limit for these compounds was 1 ng/g (1 PPB). All data were processed using PROC GLIMMIX in SAS v 9.4 (SAS Institute, Inc., Cary N.C.) with $\alpha = 0.05$.

Results and Discussion

Acephate

At 7 days after harvest, all foliar timings had higher levels of acephate than the untreated plot. The 1 PHI timing had the highest level of acephate detection, with over 25,000 ppb being detected. A similar trend was observed 1 month after harvest, however, there was no difference observed between 7 PHI and 1 PHI (Fig. 1).

Methamidophos

No detections of methamidophos were observed for the untreated plot at 7 days or 1 month after harvest. For both 7 days and 1 month after harvest, the 7 PHI timing had the highest detection of methamidophos. At 7 days after harvest, the 1 PHI timing had a higher detection level than the 60% HD timing, but there was no difference observed for these timings for the 1 month after harvest sample (Fig. 2).

Overall acephate did breakdown readily prior to harvest. Once the grain was harvested and placed into storage, no change in detection levels was observed for either acephate or methamidophos. Even with active breakdown of acephate, at all foliar timings the level of acephate or methamidophos detected was higher than what is allowed at all foreign ports.

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[1] Assistant Professor/Extension Entomologist and Program Associate, respectively, Department of Entomology and Plant Pathology, Stuttgart.

[2] Professor/Extension Entomologist, Assistant Professor/Extension Entomologist, Program Associate, Program Associate, Program Associate, and Program Associate, respectively, Department of Entomology and Plant Pathology, Lonoke.

[3] Program Associate, Department of Crop, Soil, and Environmental Sciences, Stuttgart.

[4] Graduate Assistant and Graduate Assistant, respectively, Department of Entomology and Plant Pathology, Fayetteville.

Practical Applications

Based on the work conducted in 2018, it appears that a direct application of acephate to rice will leave enough residue that it can be detected regardless of application timing. Reported detection levels from rejected barges are much lower than those observed in this study, suggesting that drift may be a large component of the barges that are being rejected. The bottom line is acephate is not labeled for use in rice, and the use of this product jeopardizes the rice industry as a whole in the mid-South. We need to be aware that if we are using acephate on other crops near rice, that there is potential to drift onto the rice and could lead to the rice being rejected when it is being sold.

Acknowledgments

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

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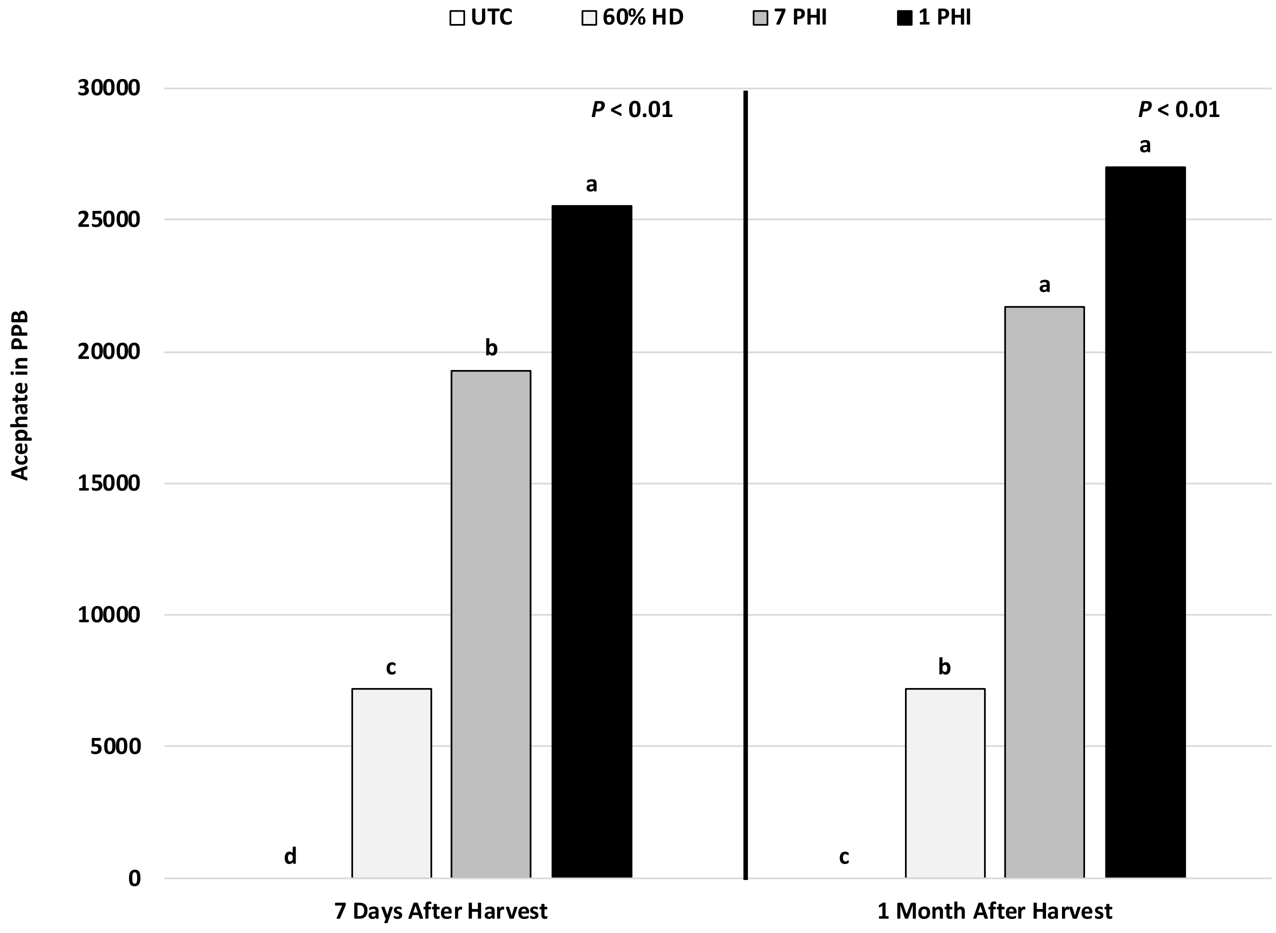

Fig. 1. Acephate detections in rice from applications made at 60% hard dough (60% HD), 7 days prior to harvest (7 PHI), and 1 day prior to harvest (1 PHI). Means followed by the same letter are not significantly different from one another at $\alpha = 0.05$. UTC = untreated check; PPB = parts per billion.

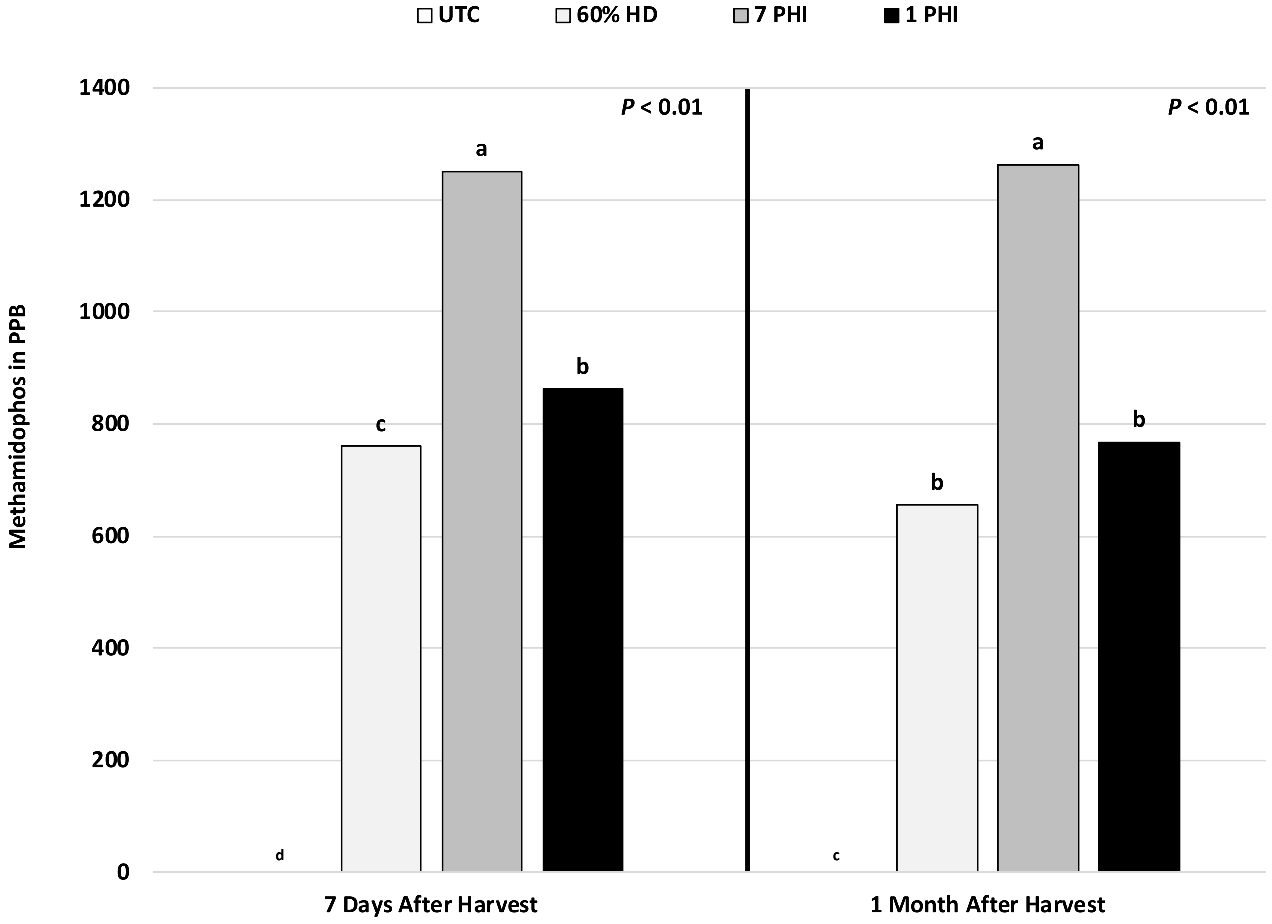

Fig. 2. Methamidophos detections in rice from applications made at 60% hard dough (60% HD), 7 days prior to harvest (7 PHI), and 1 day prior to harvest (1 PHI). Means followed by the same letter are not significantly different from one another at $\alpha = 0.05$. UTC = untreated check; PPB = parts per billion.

Impact of Defoliation on Rice for Multiple Planting Dates

S.G. Felts,[1] N.R. Bateman,[1] G.M. Lorenz,[2] B.C. Thrash,[2] N.M Taillon,[2] W.A. Plummer,[2] W.J. Plummer,[2]
J.K. McPherson,[2] T.L. Clayton,[3] C.A. Floyd,[4] and C. Rice[4]

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 armyworm. It is common to see infestations 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. Rice plants in large field plots were 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 also observed when plants were defoliated at 66% or 100% during any growth stage, with delays ranging from 2 days for defoliation occurring at the 2–3 leaf growth stage to 28 days for defoliation occurring at the green ring growth stage. Yield loss and delays in heading were greater for the June planting date compared to the April or May planting date. This data will help 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 ground, or water level if the permanent flood is established. The current threshold for armyworms in rice is based on the number of larvae per square foot, which can be difficult to determine for growers and consultants. A defoliation-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 yield and growth of rice across multiple planting dates and growth stages.

Procedures

Studies were conducted at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center in 2019 to determine the impact defoliation has on rice across multiple planting dates. Diamond was drill-seeded at 70 lb/ac on 15 April, 8 May and 1 June. Plots were 8 rows (7.5-in. spacing) by 16.5 ft. Defoliation was simulated using an electric weed eater 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 waterline. 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, Inc., Cary, N.C.) with $\alpha = 0.05$.

Results and Discussion

Little to no yield loss was observed for the 2–3 leaf, early tiller, or late tiller growth stages for the April planting, although major yield losses were observed for the green ring defoliation timing (Fig. 1). Large amounts of yield loss were observed for the May and June plantings at the late tiller and green ring growth stages (Figs. 2 and 3).

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 both the late tiller growth stage and green ring growth stage, major heading delays were observed for the May and June plantings (Table 1).

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.

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[1] Program Associate and Assistant Professor/Extension Entomologist, respectively, Department of Entomology and Plant Pathology, Stuttgart.

[2] Professor/Extension Entomologist, Assistant Professor/Extension Entomologist, Program Associate, Program Associate, Program Associate, and Program Associate, respectively, Department of Entomology and Plant Pathology, Lonoke.

[3] Program Associate, Department of Crop, Soil, and Environmental Sciences, Stuttgart.

[4] Graduate Assistant and Graduate Assistant, respectively, Department of Entomology and Plant Pathology, Fayetteville.

Practical Applications

These data will help develop a defoliation-based threshold that will ensure growers stay profitable. It will eliminate unwarranted sprays for early season defoliation and 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 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.

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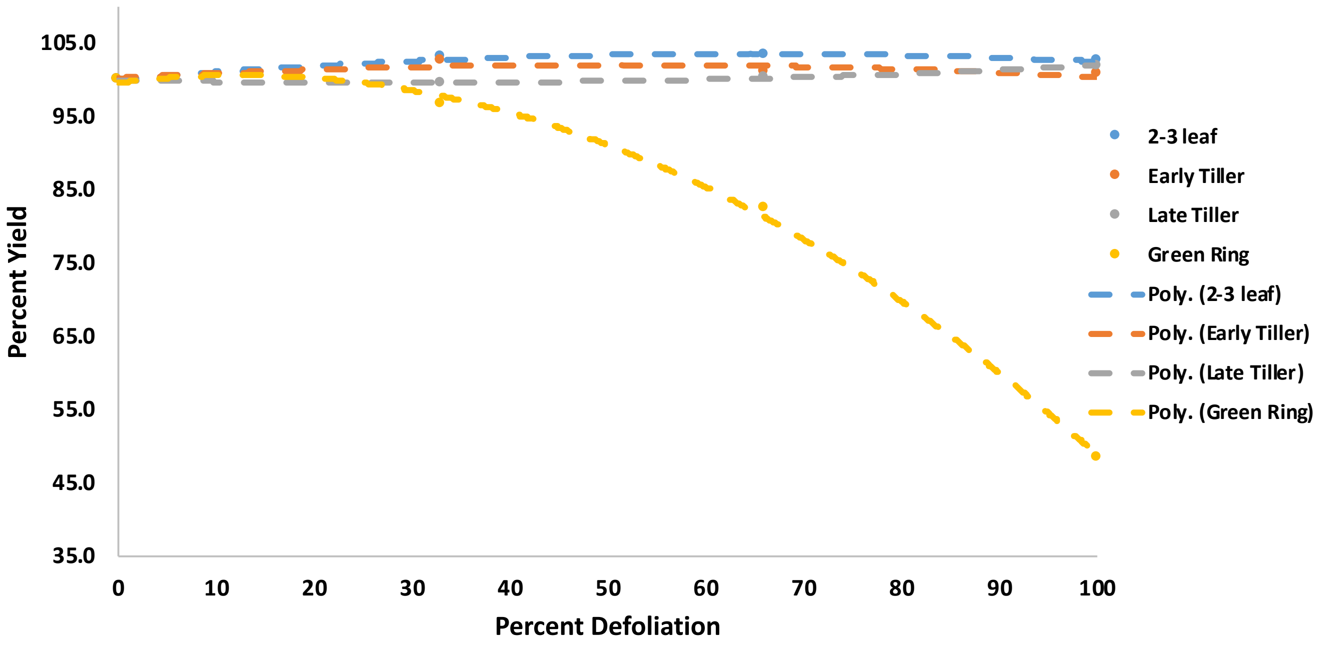

Fig. 1. Yield impacts caused by varying levels of defoliation at multiple growth stages for April planted rice.

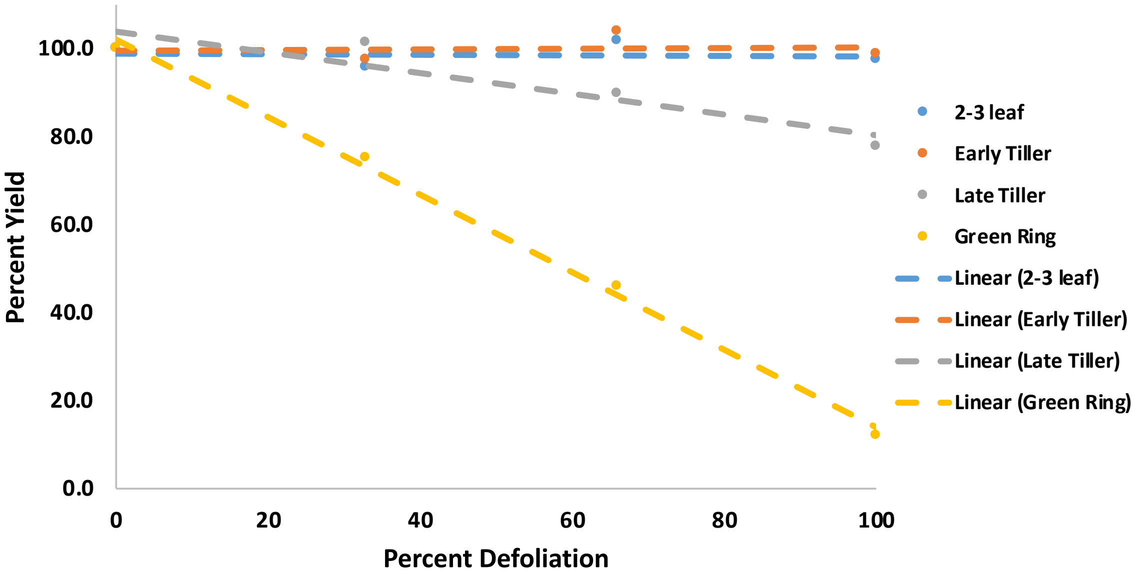

Fig. 2. Yield impacts caused by varying levels of defoliation at multiple growth stages for May planted rice.

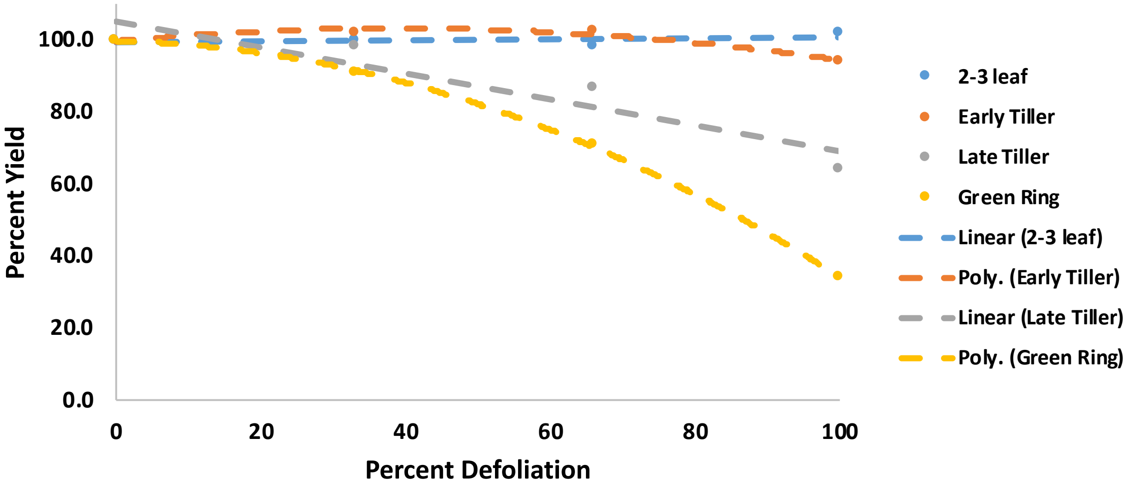

Fig. 3. Yield impacts caused by varying levels of defoliation at multiple growth stages for June planted rice.

Table 1. Days in delayed heading in rice caused by defoliation at multiple growth stages.

		Planting Date		
Growth Stage	**% Defoliation**	**April**	**May**	**June**
2–3 Leaf	0	0.0 (0.0) i†	0.0 (0.0) i	0.0 (0.0) j
	33	0.0 (0.0) i	0.0 (0.0) i	0.0 (0.0) j
	66	0.0 (0.0) i	0.0 (0.0) i	0.0 (0.0) j
	100	0.5 (0.2) hi	1.7 (0.3) h	1.3 (0.2) i
Early Tiller	0	0.0 (0.0) i	0.0 (0.0) i	0.0 (0.0) j
	33	0.8 (0.2) hi	1.8 (0.3) h	2.2 (0.3) hi
	66	1.5 (0.2) gh	2.5 (0.2) h	3.2 (0.3) h
	100	2.3 (0.2) g	4.5 (0.4) g	5.5 (0.4) g
Late Tiller	0	0.0 (0.0) i	0.0 (0.0) i	0.0 (0.0) j
	33	3.7 (0.5) f	6.5 (0.4) f	7.8 (0.6) f
	66	5.0 (0.4) e	8.0 (0.6) e	10.2 (0.6) e
	100	7.7 (0.3) d	11.5 (0.4) d	13.5 (0.6) d
Green Ring	0	0.0 (0.0) i	0.0 (0.0) i	0.0 (0.0) j
	33	9.0 (0.5) c	13.7 (0.3) c	16.3 (0.5) c
	66	11.8 (0.6) b	18.3 (0.6) b	23.2 (0.5) b
	100	15.2 (0.7) a	24.5 (0.8) a	29.8 (0.7) a
***P*-value**		<0.01	<0.01	<0.01

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

Distribution of Rice Billbug (*Sphenophorus pertinax*) and Evaluating Monitoring Systems in Furrow-Irrigated Rice

C.A. Floyd,[1] G.M. Lorenz,[2] N.R. Bateman,[3] B.C. Thrash,[2] N.K. Joshi,[1] N.M. Taillon,[2]
S.G. Felts,[3] W.A. Plummer,[2] W.J. Plummer,[2] J.K. McPherson,[2] and C. Rice[1]

Abstract

Furrow-irrigated rice production acreage is increasing in Arkansas due to potential cost savings on tillage and levee construction when compared to flood-irrigated rice. In a furrow-irrigated rice system, there is a lack of standing water across all or a portion of the field, which increases the susceptibility to rice billbug (*Sphenophorous pertinax*). Rice billbugs feed on the roots and tillers of rice plants, causing rice seed heads to abort and direct yield loss to occur. As furrow-irrigated production systems increase across Arkansas, so has the demand for rice billbug management strategies. A survey was conducted across 4 states, in 53 furrow-irrigated fields to monitor billbug distribution. Studies were also conducted in three furrow-irrigated rice fields in Arkansas to evaluate trapping methods for rice billbugs in furrow-irrigated production systems. Multiple insect trap styles were evaluated to observe how this pest enters the field.

Introduction

In the mid-southern U.S., Arkansas, Louisiana, Missouri, and Mississippi are prominent rice-growing states, responsible for 73% of total rice harvested nationally in 2019 (USDA-NASS, 2019). Furrow-irrigated rice production has increased in recent years as rice producers seek an easier and more efficient rice production practice. 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 on the levees. Without the presence of a flood and increased plant density for cover, furrow-irrigated rice has become a favorable host for billbug (Dupuy and Ramirez, 2016). No research has been conducted on rice billbug, and fundamental research is needed to understand how this pest interacts with furrow-irrigated rice. The objective of this study is to determine rice billbug distribution in the mid-southern U.S. and analyze different trapping methods to create a successful monitoring program.

Procedures

Billbug Survey

A survey was conducted in 53 furrow-irrigated rice fields in four states across the mid-southern U.S. Numerous locations were observed across Arkansas (37), Missouri (8), Louisiana (6), and Mississippi (2). Observations were taken of the surrounding landscape in the four cardinal directions of the field. At each location, 3 pink 5-gallon 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.

Monitoring Systems for Rice Billbug

An experiment was conducted at 3 furrow-irrigated rice locations in Jackson (1) and Arkansas (2) County. RiceTec RT CLXL745 hybrid was used for its high rice blast resistance and was planted at a rate of 22 lb/ac. Eight styles of traps were used to determine the best method for monitoring rice billbug entering the field which included: buckets, pitfall traps, ground covering methods, malaise traps, light traps, sticky cards, and pyramid traps. Each trap was checked weekly staring 8 May for 18 consecutive weeks.

Bucket. A series of six 5-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, where the top of the trap was 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 walk into and fall into the trap are forced to

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[1] Graduate Assistant, Assistant Professor, and Graduate Assistant, respectively, Department of Entomology and Plant Pathology, Fayetteville.

[2] Distingusihed Professor/Extension Entomologist, Assistant Professor/Extension Entomologist, Program Associate, Program Associate, Program Associate, and Program Associate, respectively, Department of Entomology and Plant Pathology, Lonoke.

[3] Assistant Professor/Extension Entomologist and Program Associate, respectively, Department of Entomology and Plant Pathology, Stuttgart.

travel into the collection container which is filled with a non-toxic pink propylene glycol solution.

Ground Cover Methods. A series of different materials were placed along the field edge and monitored weekly to determine if the 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 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 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 two collection troughs 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 powered by photoelectric sensors that respond to changes in sunlight. Photoelectric sensors were connected to a deep cycle marine battery, which provided efficient power in 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. Light traps were replicated two times 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. orange sticky cards were placed on alternating posts. Sticky cards received additional applications of insect collection adhesive. Replacement sticky cards were exchanged weekly, and previous sticky cards were removed and observed for rice billbug.

Pyramid Traps. Finally, two black pyramid insect traps were placed along the field edge. Traps consisted of two black corrugated plastic triangles standing 4 ft in height and, and staked into the soil. Pyramid traps 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, Inc., Cary N.C.).

Results and Discussion

Billbug Survey

Rice billbug damage was observed at survey locations in both Arkansas and Missouri. Billbug damage was not found in locations in Louisiana or Mississippi, though damage has been reported in these regions. Across the 53 survey locations, rice billbug damage and larvae were observed at 60% of fields. In Arkansas, 78% of fields surveyed had a presence of rice billbug within the field. Missouri's results showed 50% of fields surveyed had a billbug infestation. In furrow-irrigated rice fields that are directly bordering grassy areas, infestations of rice billbug were observed in 81% of fields surveyed. In contrast, only 7.5% of fields that were not bordering a grassy area had an infestation of rice billbug.

Billbug Monitoring

Bucket Color Preference. Across all three locations, buckets that were colored pink had consistently greater numbers of billbug gathered under them than other color variations. No differences were observed among the other colors (Fig. 1). These data suggest the color 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 99% of the 2019 total. 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 billbug than those designed for more flight prone insects. These findings suggest that rice billbugs are likely crawling to infest rice fields rather than flying.

Practical Applications

Billbugs were prone to crawl under most of the trapping systems tested. The traps that were colored pink were more attractive than all other tested colors. Currently, research is being conducted to extract sex pheromones form rice billbug 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 billbugs. This research will eventually aid Arkansas rice growers by detecting the presence of rice billbugs and employing timely management strategies in order to preserve yield.

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, Jay Coker, Taylor Helms, and Kris Keller for the use of their land, and University of Arkansas System Division of Agriculture, Arkansas Cooperative Extension Service county agents for their help with this project.

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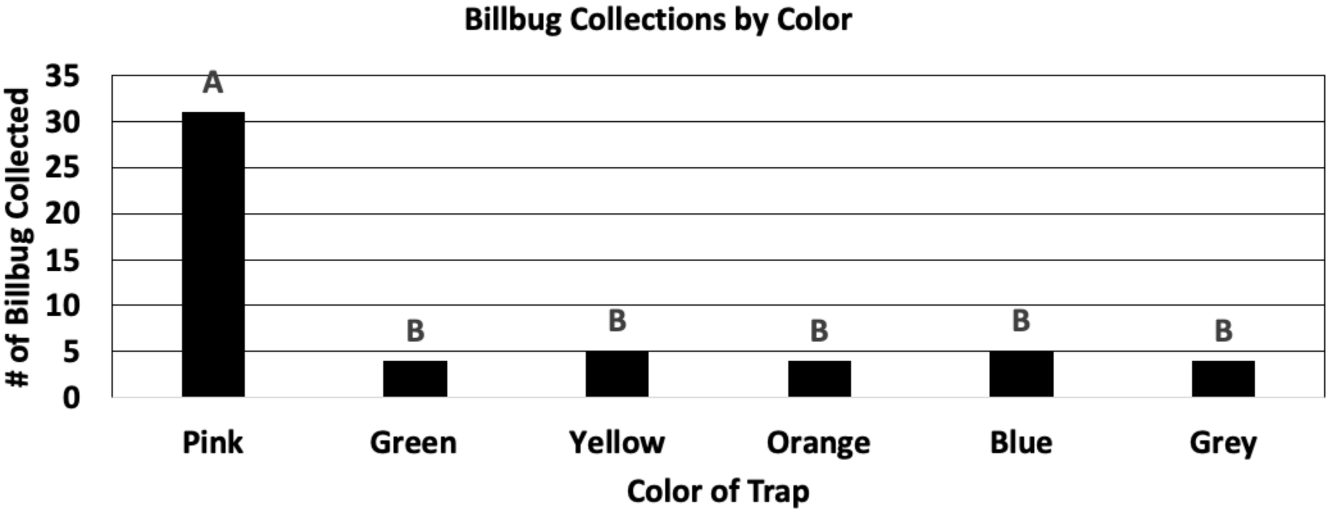

Fig. 1. Collection of Rice Billbug using different color traps. Treatments with the same letter are not significantly different according to Fisher's protected least significant difference at α = 0.05.

Table 1. Weekly percentages of Rice Billbug collections using various style traps.

	Trapping System								
Date	**Bucket†**	**Pitfall†**	**Tarp†**	**Trough†§**	**Flight Interception‡**	**Light‡**	**Sticky Cards‡**	**Pyramid‡**	**GroundCover†**
	(% of Weekly Collection Total)								
WK 1¶	0	0	0	0	0	100§	0	0	0
WK 2	100	0	0	0	0	0	0	0	0
WK 3	100	0	0	0	0	0	0	0	0
WK 4	83	0	17	0	0	0	0	0	0
WK 5	26	0	7	67	0	0	0	0	0
WK 6	63	0	0	37	0	0	0	0	0
WK 7	13	0	0	87	0	0	0	0	0
WK 8	43	0	0	57	0	0	0	0	0
WK 9	22	0	33	33	0	0	0	0	12
WK 10	33	0	0	67	0	0	0	0	0
WK 11	37	0	0	63	0	0	0	0	0
WK 12	71	0	0	29	0	0	0	0	0
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#	50	0	0	50	0	0	0	0	0
%Total	43%	7%	5%	42%	0%	1%	0%	0%	2%

† Denotes traps designed for ground active insects.

‡ Denotes traps designed for flight active insects.

§ Billbugs were collected under the trap, not by designed method.

¶ Collection date started 8 May 2019.

Collection date ended 20 August 2019.

Efficacy of Selected Insecticides for Control of Rice Stink Bug, *Oebalus pugnax*, in Arkansas, 2019

G. M. Lorenz,[1] N.R. Bateman,[2] B.C. Thrash,[1] S.G. Felts,[2] N.M. Taillon,[1] J.K. McPherson,[1]
W.A. Plummer,[1] W.J. Plummer,[1] Chase Floyd,[3] and Caleb Rice[3]

Abstract

In the last two years, over 50% of the rice acreage in Arkansas received an insecticide application for rice stink bug. Because of the significance of this pest in rice production, we continually monitor currently recommended insecticides as well as new insecticides to make the most efficient and economical recommendations for rice producers. A study was conducted to evaluate the efficacy of the most common insecticides used for rice stink bug control and to compare them with a new insecticide, not registered for use, that may provide better, long-lasting control.

Introduction

The rice stink bug, *Oebalus pugnax*, is considered a major pest of rice. In the past two seasons, over 50% of rice fields in Arkansas received an insecticide application for control of this pest. During early stages of grain development, the piercing-sucking stylet of the rice stink bug penetrates the rice hull and removes the grains' content resulting in yield loss. In the later stages of grain development, feeding causes discoloration of the kernel which is called 'pecky' rice (Swanson and Newsom, 1962).

Rice stink bugs usually move to rice from weeds or other rotational commodities during heading (Way and Bowling, 1991). Some of the alternate hosts for rice stink bug include grain sorghum, oats, rye, wheat, barnyardgrass, bearded sprangletop, dallisgrass, lovegrass, ryegrass, crabgrass, broadleaf signalgrass and several species of Panicum (Lorenz et al., 2018). Tindall et al. (2005) observed an increase in pecky rice with the presence of these weeds and an increase in unfilled kernels due to higher densities of rice stink bug.

The threshold for stink bugs in Arkansas, during the first two weeks of heading, is 5 rice stink bugs per 10 sweeps with a standard 15-inch sweep net. During the next two weeks, the threshold increases to 10 rice stink bugs per 10 sweeps. In these cases, the use of an insecticide is recommended (Lorenz et al., 2018). On average, one application is adequate for rice stink bug control. For very early and very late heading rice, multiple applications may be warranted to reduce populations lower than the action threshold (Lorenz et al., 2018).

While pyrethroids, the predominant insecticide class used for control of rice stink bug, provide adequate protection for 5 to 7 days, an insecticide that would provide longer lasting control would be advantageous for growers. The purpose of this study was to evaluate efficacy and residual control of selected insecticides for rice stink bug.

Procedures

A trial was conducted near Almyra, Arkansas on a grower field. Plot size was 15 ft by 35 ft in a randomized complete block design with 4 replications. Foliar treatments included: Experimental (2.57 oz/ac); LambdaCy 2EC (3.65 oz/ac); Mustang Maxx (4 oz/ac); and, Tenchu (8 oz wt/ac). LambdaCy and Mustang Maxx are pyrethroids and Tenchu (dinotefuran) is a neonicotinoid. All treatments were compared to an untreated check (UTC). Insecticide treatments were applied with a hand boom on 21 August. The boom was fitted with TX6 hollow cone nozzles at 19-inch nozzle spacing; spray volume was 10 gal/ac, at 40 psi. Insect counts were taken at 4, 7, 14, and 18 days following treatment by taking 10 sweeps per plot with a standard sweep net (15-inch diameter). Due to rainfall, we did not collect data at 10 days post treatment. Data were processed using Agriculture Research Manager version 9, analysis of variance, and Duncan's New Multiple Range Test ($P = 0.10$) to separate means.

Results and Discussion

At 4 days after application, all treatments reduced rice stink bug adults and nymphs compared to the untreated check. The untreated had 16 rice stink bugs per 10 sweeps, just over 3X the threshold of 5 rice stink bugs per 10 sweeps. The experimental insecticide had fewer stink bugs compared to all other treatments (Fig. 1). A similar trend was observed at 7 days after application and continued even through 14 days with all treatments having fewer rice stink bugs than the untreated check (Figs. 2 and 3). At 18 days post application, only the experimental treatment kept populations below the threshold of 10 stink bugs per 10 sweeps (Fig. 4). In a grower field, a second application would have been required for all treatments except the experimental.

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[1] Distinguished Professor/Extension Entomologist, Assistant Professor/Extension Entomologist, Program Associate, Program Associate, Program Associate, and Program Associate, respectively, Department of Entomology and Plant Pathology, Lonoke.

[2] Assistant Professor/Extension Entomologist, and Program Associate, respectively, Department of Entomology and Plant Pathology, Stuttgart.

[3] Graduate Assistant and Graduate Assistant, respectively, Department of Entomology and Plant Pathology, Fayetteville.

Practical Applications

Rice producers have limited options for control of rice stink bug, but none with long-term residual control. In most cases only one application is needed for control of rice stink bug; but for very early and very late planted rice, this may not be the case. For these acres, a product with long residual control is needed. Currently there are no labeled products for rice stink bug that can consistently provide the control needed for rice stink bug past 7–14 days. However, the experimental treatment in this study appeared to have much more consistent residual control of rice stink bugs. This will hopefully allow our growers to be able to make one application in problematic fields that would typically require two or even three applications for rice stink bug.

Acknowledgments

The authors would like to 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. We would also like to thank Sam Tarkington for the use of his land.

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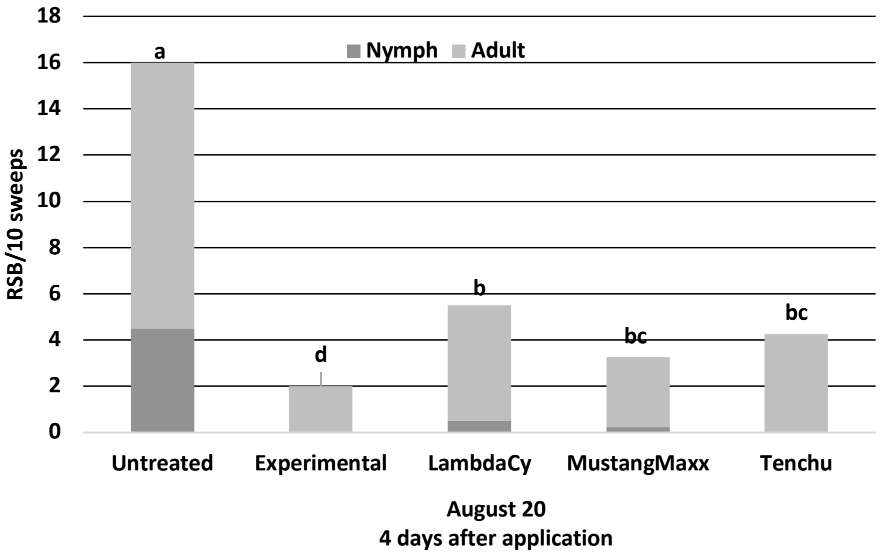

Fig. 1. Efficacy of selected insecticides at 4 days after application for control of rice stink bug (RSB). Means followed by the same letter are not significantly different.

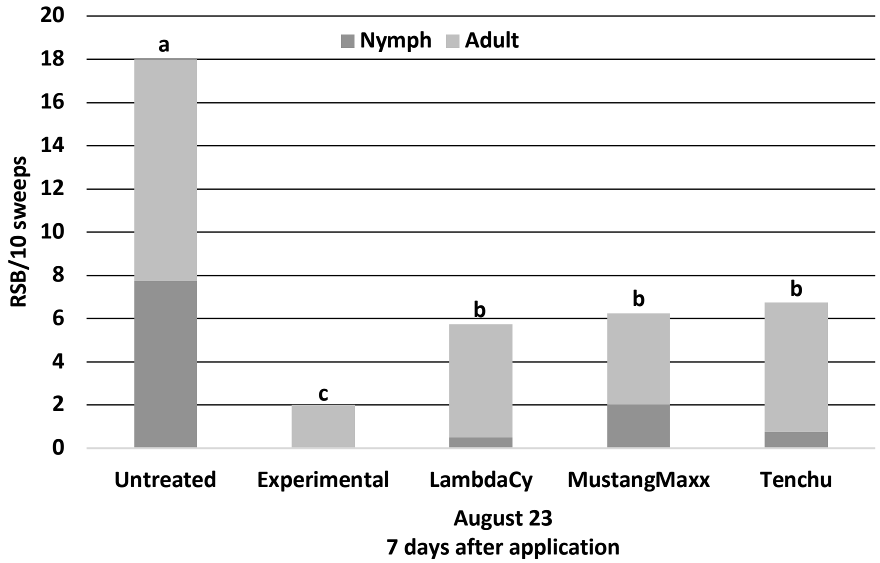

Fig. 2. Efficacy of selected insecticides at 7 days after application for control of rice stink bug (RSB). Means followed by the same letter are not significantly different.

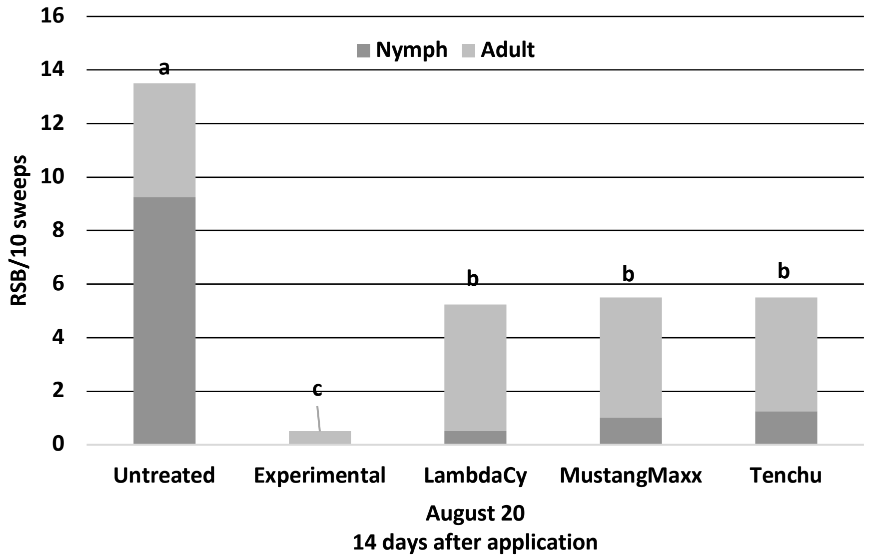

Fig. 3. Efficacy of selected insecticides at 14 days after application for control of rice stink bug (RSB). Means followed by the same letter are not significantly different.

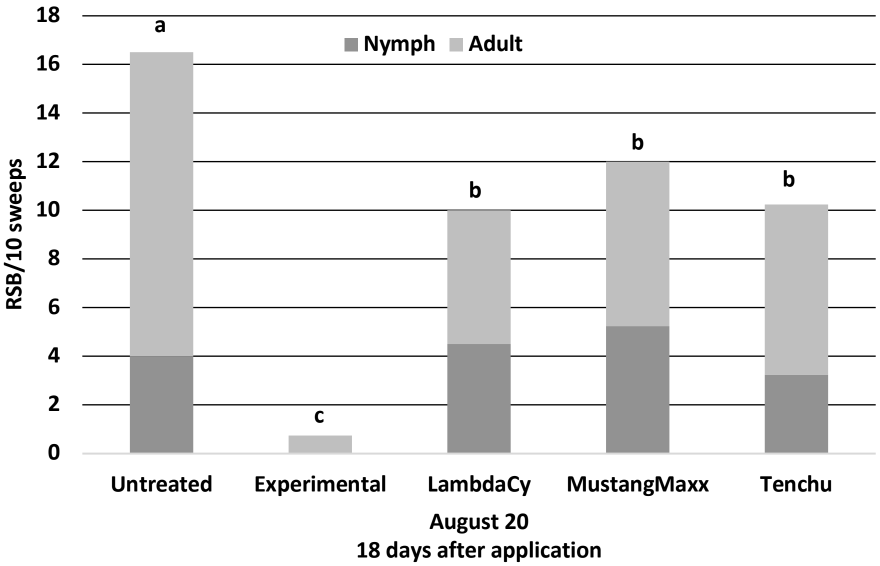

Fig. 4. Efficacy of selected insecticides at 18 days after application for control of rice stink bug (RSB). Means followed by the same letter are not significantly different.

Preliminary Observations of Potential Tolerance/Resistance to Pyrethroids in Rice Stink Bugs in Arkansas

G.M. Lorenz,[1] N. Joshi,[2] N.R. Bateman,[3] B.C. Thrash,[1] N.M. Taillon,[1] S.G. Felts,[3]
W.A. Plummer,[1] W.J. Plummer,[1] J.K. McPherson,[1] C. Floyd,[2] and C. Rice[2]

Abstract

Bioassays of field collected rice stink bugs were conducted in the laboratory. Rice stink bugs are an important pest of rice once the panicle has emerged. Bioassays of field collected rice stink bugs were conducted in the laboratory from a field where immatures survived multiple applications of a pyrethroid. In direct exposure bioassays, no more than 60% mortality was reached at the 1x rate (1.86 oz). In residual exposure bioassays, only 32% mortality was reached at the 1x rate. A 4x rate (7.44 oz) was required in both bioassays to reach 100% mortality. These results indicate that pyrethroid insecticide resistance may become a problem in Arkansas. These preliminary results indicate further testing is needed to determine future direction.

Introduction

The rice stink bug (RSB), *Oebalus pugnax*, is a major insect pest of rice in Arkansas. In recent years, approximately 50% of acres were treated for this pest (N.R. Bateman, pers. comm.). Rice stink bug typically causes yield and quality losses during the first two weeks after heading and primarily quality losses (pecky rice) during the third and fourth weeks after heading. An insecticide application is recommended if stink bug densities average 5 or more per 10 sweeps during the first 2 weeks after heading, or an average of 10 or more per 10 sweeps are found during the third and fourth week after heading.

Pyrethroids are used in over 99% of all applications targeting rice stink. Lambda-cyhalothrin (Warrior II, Silencer, LambdaCy, Kendo, Lambda Star, etc.) is the predominant pyrethroid used. Other pyrethroids labeled include zeta-cypermethrin (Mustang Maxx) and gamma-cyhalothrin (Declare or Prolex). In recent years, a neonicotinoid, dinotefuran (Tenchu), was labeled, but the cost is much higher compared to the pyrethroids.

Although resistance to pyrethroids with rice stink bugs has not been observed in Arkansas, there have been reported problems with resistance in Texas (Miller et al., 2010; Blackman et al., 2015). The purpose of this study was to determine if a field population found in Arkansas may be indicating a problem developing with pyrethroid insecticide resistance to rice stink bug.

Procedures

A field population of rice stink bug was collected from a rice field planted to hybrid RT Gemini 214 CL on 29 May. The field was located south of Jonesboro near Otwell, Arkansas on Highway 49. The field had received four lambda-cyhalothrin applications on 21 and 27 August and 12 and 17 September. Following the 4th application at 5 days post treatment, the field averaged just over 18 rice stink bugs per 10 sweeps, 9.3 nymphs and 9.0 adults per 10 sweeps. The presence of nymphs following an insecticide application is often an indicator of some kind of efficacy problem. We collected ~450 rice stink bugs with sweep nets from the field. Stink bugs were immediately transferred to large rearing cages with rice plants. The rice stink bugs were then transported to the laboratory at the University of Arkansas System Division of Agriculture for bioassays. We assessed mortality of RSB to lambda-cyhalothrin (Warrior II), at 0.25X, 0.5X, 1X, 2X and 4X rate. The application rates were: 0 (control, only water), 0.46 (0.25X), 0.93 (0.5X), 1.86 (1X), 3.72 (2X), and 7.44 (4X) oz/ac in two different bioassays. In the first bioassay, we assessed mortality after direct pesticide exposure with each treatment applied to RSB adults using a spray tower designed to simulate field applications. In the second bioassay, the residual toxicity of these application rates to RSB adults was assessed by application on Petri dishes with RSB adults released into the Petri dish after two hours. In both bioassays, mortality of RSB was recorded at 24 and 48 hours after the treatment.

Results and Discussion

When rice stink bug populations are high in Arkansas, it is not uncommon for growers to treat for rice stink bug only to see populations increase in the field at 4–7 days post application. However when this occurs, it is usually adults migrating from other fields or from wild hosts. In this particular situation, the consultant that alerted us to the problem indicated that nymphs were also present in high numbers. This is an obvious indication that the rice stink bug nymphs survived the insecticide application or possibly that an application error may have occurred. In this case, repeated applications were made and the applications

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[1] Distinguished Professor/Extension Entomologist, Assistant Professor/Extension Entomologist, Program Associate, Program Associate, Program Associate, and Program Associate, respectively, Department of Entomology and Plant Pathology, Lonoke.

[2] Associate Professor, Graduate Assistant and Graduate Assistant, respectively, Department of Entomology and Plant Pathology, Fayetteville.

[3] Assistant Professor/Extension Entomologist, and Program Associate, respectively, Department of Entomology and Plant Pathology, Stuttgart.

were witnessed and we were able to conclude that application was not an issue. In a final effort to make sure that there was not a water pH issue, we made backpack applications with water from another source with a different pH. After these applications were made, nymphs and adults were still present indicating a possible resistance issue and not an application issue.

Direct Contact Exposure Bioassay

At 24 hours post exposure, the 0.25X rate had no mortality while the 0.5X rate had less than 20% mortality (Fig. 1). Further, there was only 44% mortality at the 1X rate of 1.86 oz, and a 4X rate (7.44 oz) was required to reach 100% mortality. At 48 hours, there was a similar trend with increases over the 24 hour post exposure (Fig. 2). Mortality increased at the 1X rate to just under 60% and the 2X rate reached 80% mortality.

Residual Exposure Bioassay

At 24 hours, negligible mortality was observed with the 0.25X and 0.5X rate and only 32% mortality at the 1.0X rate (Fig. 3). Similar to direct contact exposure, a 4.0X rate was required to reach 100% mortality. A similar trend was observed at 48 hours, with less than 20% mortality observed at the 0.25X and 0.5X rates (Fig. 4). Less than 50% mortality was observed at the 1.0X rate, while at the 2X rate 90% mortality was observed.

Following our results, we visited with other consultants around the area where we saw the problem. Many of them indicated they also saw nymph survival to some degree following pyrethroid applications for rice stink bug in the area.

Practical Applications

These results appear to indicate that pyrethroid insecticide tolerance/resistance may become an issue for rice producers in Arkansas. It is important to realize that these results are strictly preliminary and that more work must be done before we can definitively tell whether a problem is developing. We plan to expand our studies in 2020. If pyrethroid resistance is developing, we will need to educate our growers and consultants on insecticide resistance management and managing this important insect pest of rice.

Acknowledgments

The authors wish to express appreciation to Randy Chlapecka for alerting us to this potential issue. We also express our appreciation for funding and support from the Arkansas rice growers administered through the Rice Research and Promotion Board. Support was also given by the University of Arkansas System Division of Agriculture.

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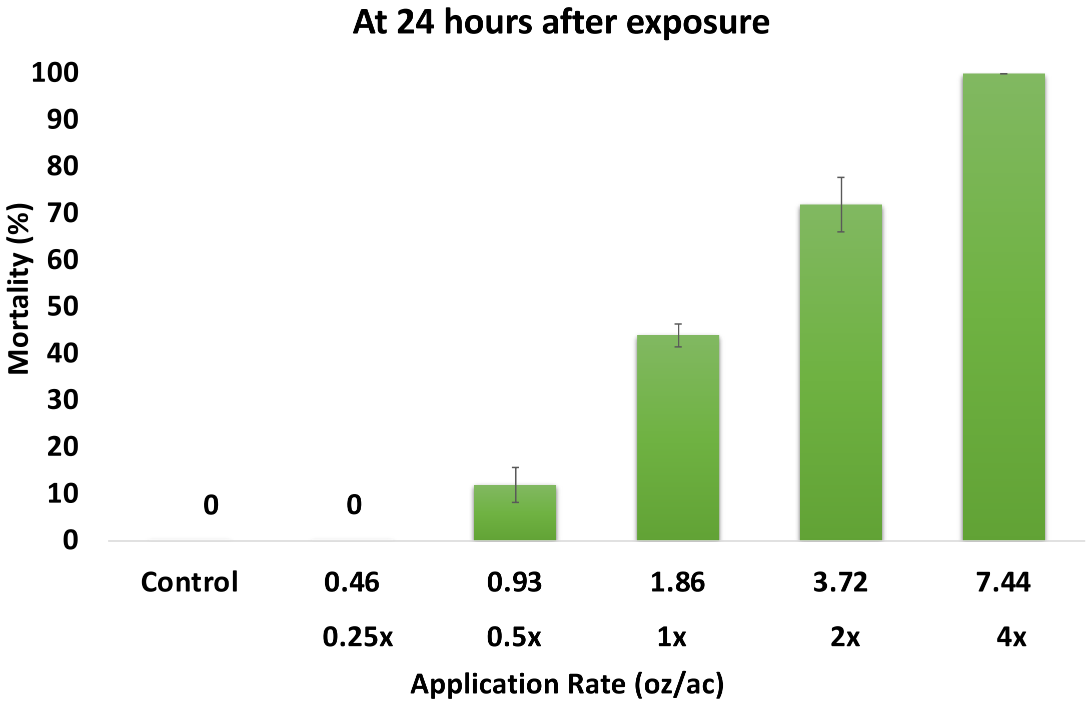

Fig. 1. Direct contact exposure of different rates of lambda-cyhalothrin (Warrior II) on rice stink bugs and resulting mortality at 24 hours, at Weiner, Arkansas.

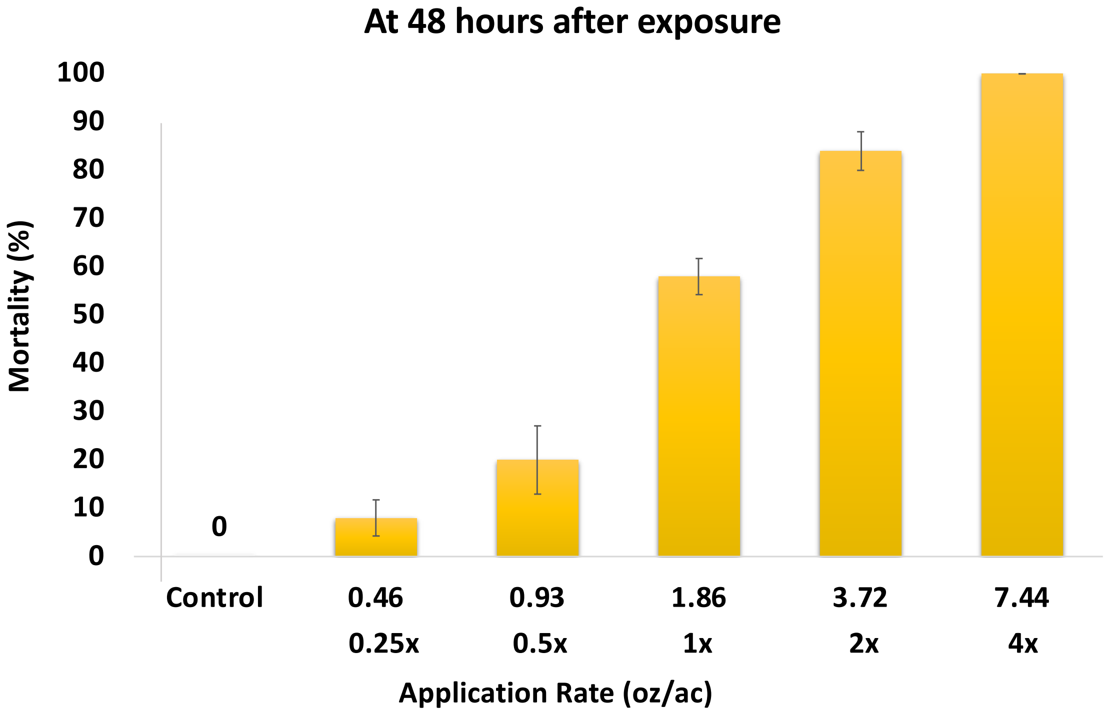

Fig. 2. Direct contact exposure of different rates of lambda-cyhalothrin (Warrior II) on rice stink bugs and resulting mortality at 48 hours, at Weiner, Arkansas.

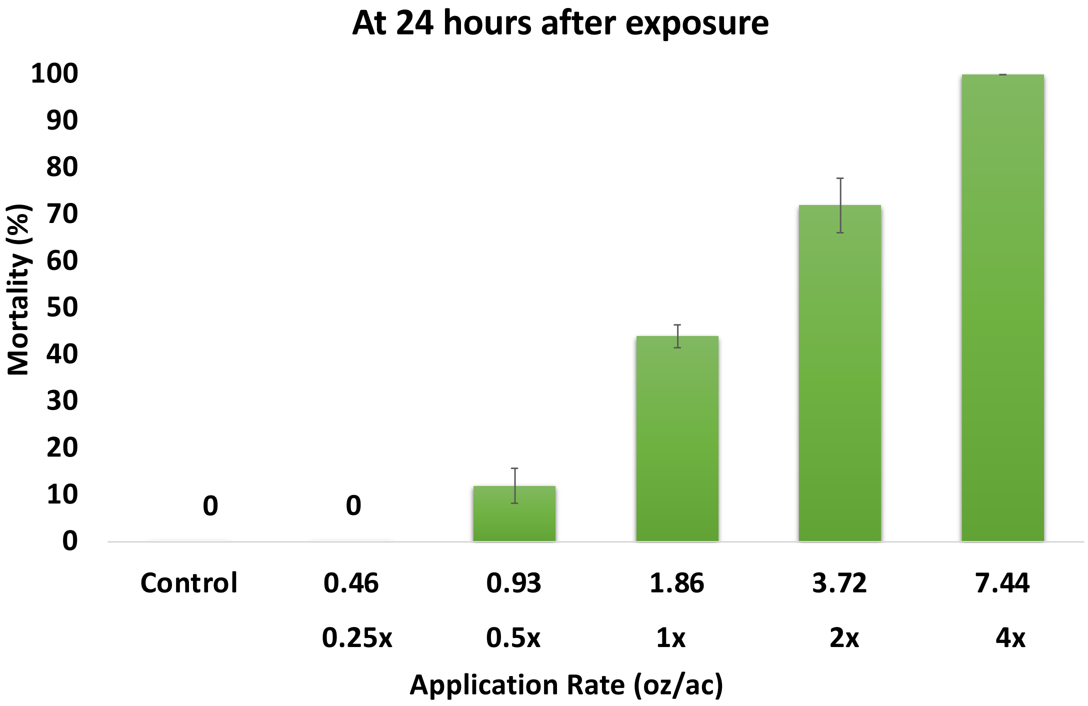

Fig. 3. Residual exposure of different rates of lambda-cyhalothrin (Warrior II) on rice stink bugs and resulting mortality at 24 hours, at Weiner, Arkansas.

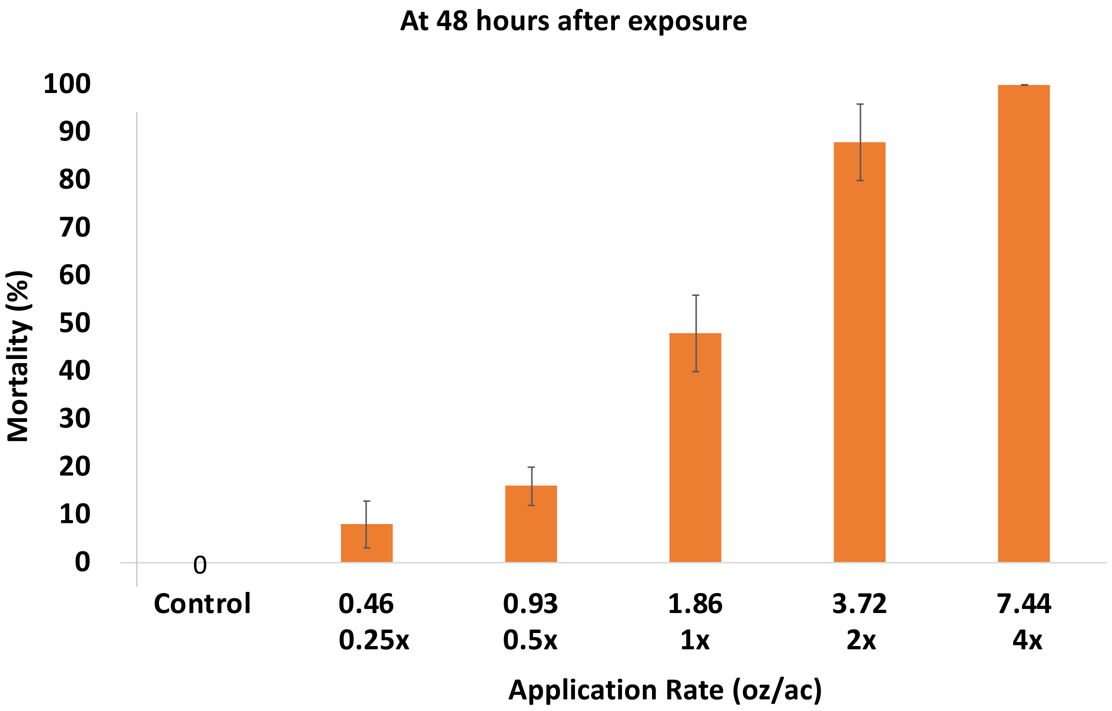

Fig. 4. Residual exposure of different rates of lambda-cyhalothrin (Warrior II) on rice stink bugs and resulting mortality at 48 hours, at Weiner, Arkansas.

Evaluation of a Seed Treatment for Safening Rice to Rates of Soil-Applied Acetochlor

T.H. Avent,[1] J.K. Norsworthy,[1] C.B. Brabham,[1] L.B. Piveta,[1] and M.C. Castner[1]

Abstract

Warrant® (microencapsulated, ME) and Harness® (emulsified concentrate, EC) are both formulations of acetochlor. Currently, no acetochlor formulation is labeled for use in rice production; however, pretilachlor, a less efficacious, chloroacetamide herbicide, is labeled for use in Asian rice production systems when combined with applications of fenclorim, a product developed by Ciba Geigy in the 1980s. Field trials were conducted in 2019 at the Milo J. Shult Agricultural Research and Extension Center, Fayetteville, to evaluate the safening effects of fenclorim as a seed treatment when applying acetochlor. The experiment was designed as a split plot with the whole-plot factor being fenclorim seed treatment (0%, 0.025%, and 0.25% lb ai/lb of seed) and subplot factors being two acetochlor formulations (ME and EC) and three acetochlor rates (0.28, 0.56, and 1.12 wt/wt-seed) applied preemergence (PRE) and delayed preemergence (DPRE). Non-herbicide treated plots also included fenclorim at each rate. As rate of acetochlor increased, injury to rice likewise increased. Higher rates of fenclorim decreased injury to rice, indicative of a safening effect. As acetochlor rate decreased, stand loss diminished and was comparable to the non-treated at the highest rates of the safener. Likewise, switching from EC to ME formulation caused less injury to rice. The highest rate of fenclorim (0.25% wt/wt-seed) in combination with the ME formulation of acetochlor at 1.12 lb ai/ac resulted in only 9% injury to rice; whereas the EC formulation at the same acetochlor rate caused 56% injury in the absence of fenclorim. Furthermore, applications made DPRE exhibited higher safety than that of the PRE applied treatments. This research clearly shows that fenclorim applied as a seed treatment in combination with a ME formulation of acetochlor applied DPRE can result in commercial safety to the herbicide in drill-seeded rice.

Introduction

Acetochlor is a very long-chain fatty acid inhibitor (Group 15) belonging to the chloroacetamide chemical family produced as either a microencapsulated (ME) or emulsified concentrate (EC) formulation (Babczinski et al., 2012). Chloroacetamide applications are currently not labeled for United States rice production; however, they are widely used in Asian rice production systems in combination with a safener (Quadranti and Ebner, 1983). In previous research conducted at the University of Arkansas System Division of Agriculture (unpublished, 2018), acetochlor provided substantial weed control, comparable to clomazone, applied preemergence (PRE), delayed-preemergence (DPRE), and postemergence (POST). The PRE and DPRE application timings provided better weed control when compared to applications made POST; however, concern for injury to rice was questioned when stand loss and phytotoxicity was observed after applications at either the PRE or DPRE application timing. Acetochlor has also exhibited control of barnyardgrass (*Echinochloa crus-galli*), sprangletop (*Leptochloa* sp.), and weedy rice (*Oryza sativa*), three of the five most problematic weeds for Arkansas rice producers and can provide control of several other grasses and small seeded broadleaves (Norsworthy et al., 2007). Applications of acetochlor can provide Arkansas producers a new site of action not currently available in rice production systems; however, safety to the crop is the primary concern for applications made during the growing season.

Fenclorim is a product developed and released by Ciba Geigy in 1983 to be used in Asian rice production systems in combination with pretilachlor, another chloroacetamide (Quadranti and Ebner, 1983). Initial treatments of pretilachlor were premixed with fenclorim as an antidote to the herbicide to effectively safen rice to applications. Currently, rice seeds are soaked in a solution of fenclorim and water before water seeding or transplanting rice and still provide sufficient safety to the crop (Chen et al., 2012). Fenclorim safens applications of chloroacetamides due to the similar structure to the herbicide molecule (Usui et al., 2000). This similar structure triggers a response within the plant to overexpress genes responsible for producing glutathione-s-transferase (GST), and this overproduction of GST rapidly detoxifies chloroacetamides within the rice plant. Due to the similar structure of acetochlor and pretilachlor, the purpose of this experiment was to determine if fenclorim would effectively safen applications of acetochlor to rice.

Procedures

The field study was conducted at the Milo J. Shult Agricultural Research and Extension Center, Fayetteville, Arkansas in the summer of 2019. The primary focus was to determine if fenclorim would effectively safen applications of acetochlor regardless of formulation or rate. Acetochlor was applied in two formulations (ME or EC) at rates of 0.28, 0.56, and 1.12 lb ai/ac. Seeds of rice were also treated at 0%, 0.025%, and 0.25% wt/wt of fenclorim/seed. The rice variety Diamond was planted at 22 seeds/ft of row in 6 × 5 ft plots. Each whole plot also had subplots of fenclorim treated seeds at each respective rate. For the experiment, the acetochlor was applied such that the coleoptile was emerging

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[1] Graduate Assistant, Distinguished Professor, former Post-doctoral Associate, Program Associate, Graduate Assistant, respectively, Department of Crop, Soil, and Environmental Sciences, Fayetteville.

when the acetochlor was activated; thus, fenclorim was imbibed by the seed before the acetochlor was activated. Applications were made to the soil surface using a CO_2-pressurized backpack sprayer at 15 gal/ac.

Injury assessments were collected 14 and 21 days after treatment (DAT) along with stand counts in each plot 14 DAT. Injury assessments, relative to the nontreated, were rated on a scale from 0% to 100%, with 0% being no injury and 100% being complete plant death. Stand counts of the entire subplots were measured and made relative to the nontreated on a 0–100% scale with 0% being no stand loss and 100% being complete stand loss. All data were analyzed and subjected to analysis of variance and means were separated by Fisher's protected least significant difference ($\alpha = 0.05$).

Results and Discussion

Main effects of acetochlor, formulation, and fenclorim were observed at both 14 and 21 DAT. At 21 DAT across fenclorim rate and formulation, injury averaged across treatments was 9%, 11%, and 35% for acetochlor rates of 0.28, 0.56, and 1.12 lb ai/ac. Fenclorim effectively reduced injury from 30% to 7% across formulations and rates of acetochlor. At 14 DAT averaged across rate and fenclorim, the EC formulation reduced rice stands by 19%; while ME formulations only reduced stand by an average of 7%. This indicates that fenclorim does not sufficiently safen applications of acetochlor in its EC formulation; therefore, treatment evaluations pertaining to EC formulations were excluded to better analyze the ME treatments. At the highest rate of fenclorim (0.25%) and highest rate of ME acetochlor (1.12 lb/ac), injury and stand reduction were both <10% while in the absence of fenclorim, injury and stand reduction were 30% and 15%, respectively (Figs. 1 and 2). This safening effect indicates commercial tolerance of rice to applications provided the ME formulation of acetochlor is used, a rate of ≤1.12 lb ai/ac of acetochlor, and a fenclorim seed treatment of 0.25% wt/wt-seed.

Practical Applications

Acetochlor (Warrant) would be a new site of action not currently allowed for U.S. rice production. Acetochlor would allow growers to control problematic weeds such as weedy rice, sprangletop species, and barnyardgrass. The safening effects observed are also non-traited and directly applied to the seed coat of the rice crop; therefore, outcrossing into the weedy rice population and safening weedy rice to acetochlor applications is of no concern. Furthermore, applications of fenclorim would allow for applications as early as DPRE to provide enhanced weed control with commercial safety to rice.

Acknowledgments

We would like to thank Gus Lorenz for assisting us with the treatment of the rice seed and the Rice Research and Promotion Board for their support of weed management research.

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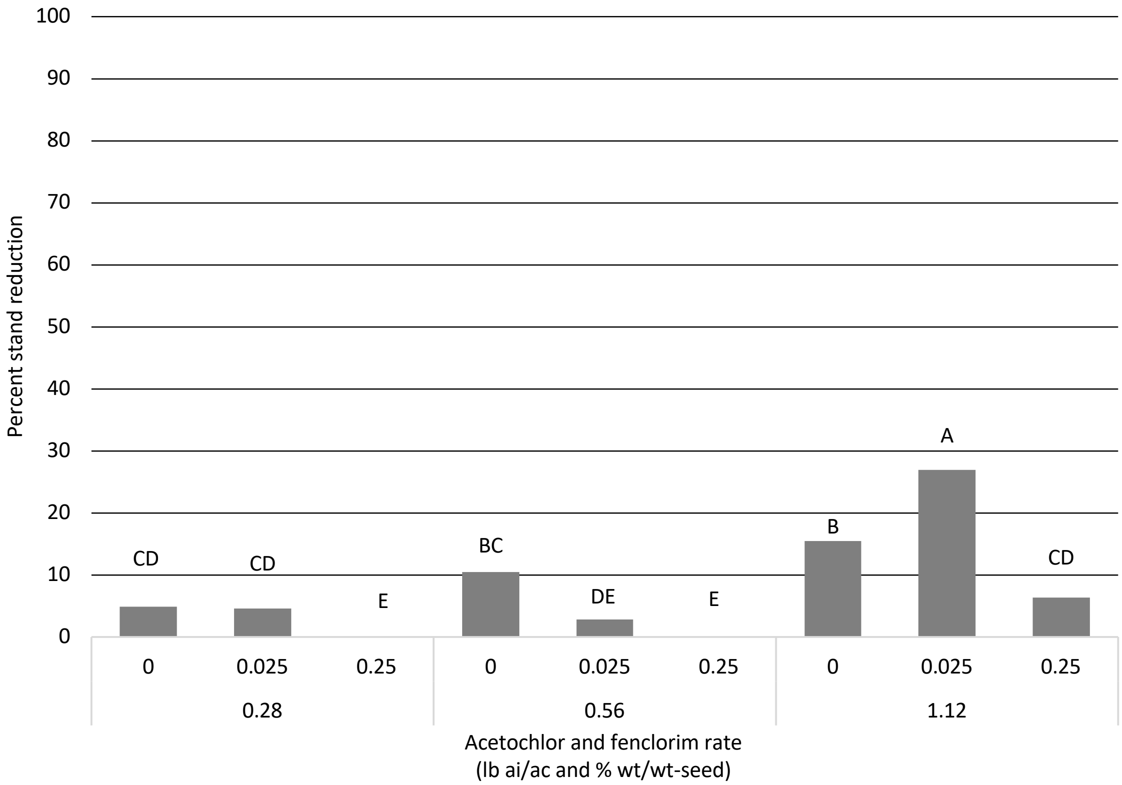

Fig. 1. Assessment of stand reduction by acetochlor and fenclorim rate 14 days after treatment to Diamond rice cultivar. Treatments with the same lowercase letter are not significantly different, separated using Fisher's protected least significant difference at α = 0.05.

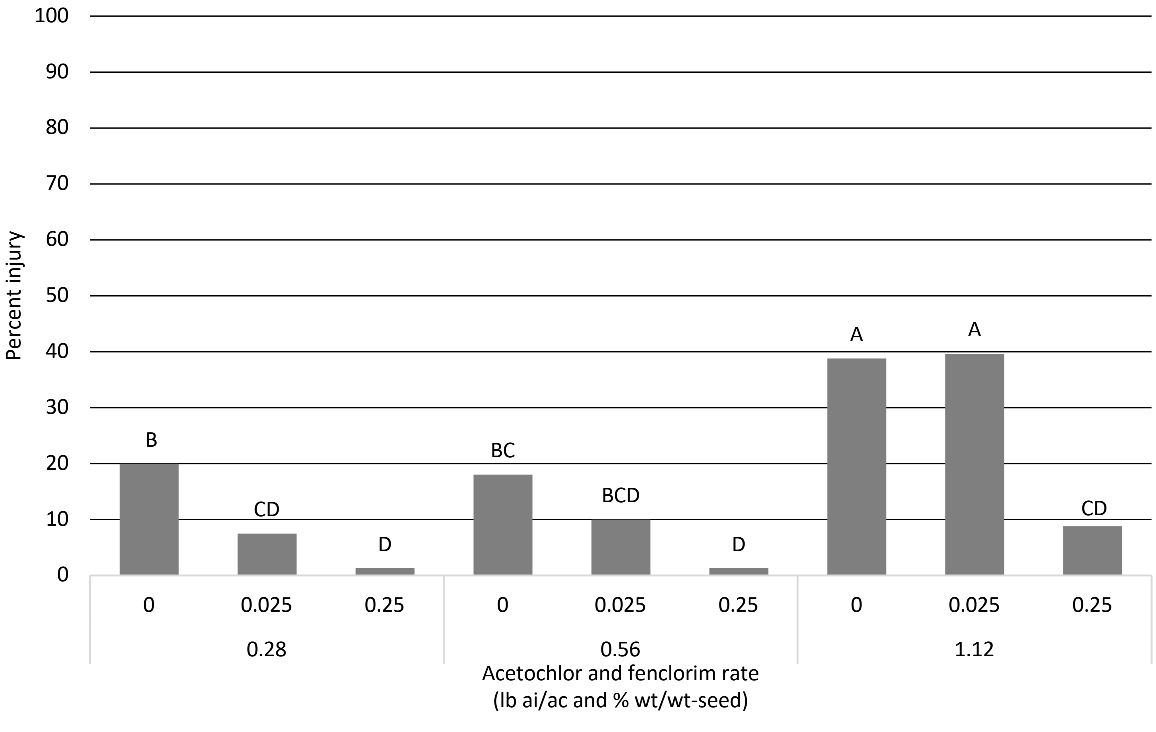

Fig. 2. Assessment of rice injury by acetochlor and fenclorim rate 21 days after treatment to Diamond rice cultivar. Treatments with the same lowercase letter are not significantly different, separated using Fisher's protected least significant difference at α = 0.05.

Using Florpyrauxifen-benzyl to Control Palmer Amaranth in Furrow-Irrigated Rice

J.W. Beesinger,[1] J.K. Norsworthy,[1] and L.T. Barber[2]

Abstract

Furrow-irrigated rice acres have been increasing in Arkansas over the last 5 years, but options for weed control are limited. Palmer amaranth, a weed previously limited to levees in rice production, is an unprecedented problem in furrow-irrigated practices because of the aerobic conditions created. A field study was designed to optimize Palmer amaranth control utilizing rates and timing of applications of Loyant (florpyrauxifen-benzyl) at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Research and Extension Center in Marianna, Arkansas. The experiment was designed as a two-factor factorial randomized complete block design. No significant interaction between rate and timing was observed. However, the main effects of rate and timing were significant. Control of Palmer amaranth increased as the rate of florpyrauxifen-benzyl increased from 3 to 16 fl oz/ac. Control was optimal if florpyrauxifen-benzyl was applied before Palmer amaranth reached a height of 20 inches, averaged over Loyant rates. The experiment shows that Loyant, when used as part of a herbicide program, can be effective against Palmer amaranth in furrow-irrigated rice acres.

Introduction

With furrow-irrigated rice gaining popularity in the state of Arkansas, new problems are presenting themselves for growers in the mid-South. Furrow-irrigated rice constituted 6.8% of total rice acres in Arkansas as of 2019 with the total number of acres predicted to rise in the near future (Hardke, 2019). Dry-seeded, flood-irrigated rice produces an anaerobic environment unsuitable for the germination or survival of many weed species. However, furrow-irrigated practices create the near perfect conditions for the germination and growth of the most troublesome weed species of cotton and soybean, including Palmer amaranth (*Amaranthus palmeri*) (Van Wychen, 2016). Because of herbicide resistance and regulations, options for control are limited in certain areas of the state. Florpyrauxifen-benzyl (Loyant), a group-4 synthetic auxin herbicide for control of grass and broadleaf species in flooded rice, has been shown to have effectively controlled Palmer amaranth when applied to rice levees. It is unknown what rates and timings are most efficient for control of Palmer amaranth in furrow-irrigated rice.

Procedures

A field experiment was conducted at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Center in Marianna, Arkansas to determine the optimum rate and timing of a florpyrauxifen-benzyl application on furrow-irrigated rice to control Palmer amaranth. Gemini rice was planed at 11 seeds per foot and divided into 25 ft × 6-ft plots. Plots were irrigated to saturation every three days. The experiment was arranged as a two-factor randomized complete block design with four replications, with the factors being the components rate and timing. Florpyrauxifen-benzyl was applied at rates of 3, 6, 10, and 16 fl oz/ac on different growth stages of Palmer amaranth. All applications made included pendimethalin to minimize further emergence and 8 fl oz/ac methylated seed oil as an adjuvant. Palmer amaranth heights were taken at the timing of every application. Following each application timing, Palmer amaranth control ratings were taken every 7 days until 45 days after treatment, with 0% indicating no control and 100% representing total weed control. The rice was harvested at maturity to observe yield differences between treatments relative to one treatment that was kept weed free by hand.

Results and Discussion

There was no interaction between Loyant rate and timing for Palmer amaranth control. Palmer amaranth control increased with size until plants reached a height of 20 inches (Table 1). After 20 inches, control decreased rapidly. In respect to florpyrauxifen-benzyl rate, control increased as rate increased. Loyant at 3 fl oz/ac controlled Palmer amaranth 83% whereas the 16 fl oz/ac rate provided 90% control, averaged over application timings. The rates of 10 fl oz/ac and 16 fl oz/ac provided similar levels of control, meaning that the lower rate of 10 fl oz/ac is just as effective as the higher rate. There were no differences in grain yield across Loyant rates, when averaged across application timings (Table 2). However, yield did decline as the Loyant application was delayed, with a yield loss of 18% observed when Loyant was applied 35 days after planting.

Practical Applications

Because of data produced by this trial, we can determine that applications of florpyrauxifen-benzyl at 10 fl oz/ac can result in sufficient control of Palmer amaranth less than 20 inches in height. Applications should be made with a residual herbicide and as a

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

[2] Extension Weed Scientist, Newport Extension Center, Lonoke.

part of a program instead of as a salvage herbicide option. When used at a rate lower than labeled, florpyrauxifen-benzyl should be used alongside a graminicide to not select for resistance in grass species as well. Applications should also be made as early as possible in order to avoid reductions in yield.

Acknowledgments

We would like to thank the staff of the University of Arkansas System Division of Agriculture's Altheimer Lab and of the Lon Mann Cotton Research Center, as well as the Arkansas Rice Research and Promotion Board for their work and support in producing this research.

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Table 1. Palmer amaranth control 28 days after treatment and relative yield separated by Palmer amaranth size at the timing of application averaged across rate.

Palmer amaranth size	Control 28 DAT†	Relative yield
(in.)	(%)	(%)
<5	84 bc‡	97 a
8–10	87 ab	92 ab
14–20	93 ab	88 ab
>20	77 c	82 b

† DAT = days after treatment.

‡ Letter designations denote significant differences.

Table 2. Control of Palmer amaranth 28 days after treatment and yield relative to weed free control by florpyrauxifen-benzyl rate averaged across application timing.

Rate of florpyrauxifen-benzyl	Palmer amaranth control 28 DAT†	Relative yield
fl oz/ac	(%)	(%)
3	83 b‡	85§
6	82 b	96
10	87 ab	91
16	90 a	88

† DAT = days after treatment.

‡ Letter designations denote significant differences.

§ Treatments are statistically similar when evaluated with a *P*-value of 0.05.

Evaluation of Dicamba Exposure on Reproductive Rice

M.C. Castner,[1] J.K. Norsworthy,[1] J.A. Patterson,[1] T. Butts,[2] and O.W. France[1]

Abstract

Engenia and XtendiMax with VaporGrip are labeled dicamba products for preemergence and postemergence control of broadleaf weeds in XtendFlex cotton and Roundup Ready 2 Xtend soybean. Despite the efficacy of dicamba on problematic weeds in the mid-South, labeled applications of Engenia and XtendiMax in both cotton and soybean have presented major concerns for off-target movement, primarily to non-dicamba-resistant soybean. Extensive research has been published regarding the effects of sublethal concentrations of dicamba at multiple growth stages in soybean; however, there is limited research investigating the impact of dicamba on reproductive rice. To determine the potential consequences of dicamba drift rates on reproductive rice, an experiment was conducted near Stuttgart, Arkansas in 2018 and 2019. Dicamba at rates of 1, 1/10, 1/100, and 1,1000X, with 1X being 227 g ae/ac, were applied to rice at three reproductive growth stages (late boot, panicle exertion, and anthesis). Treatments were arranged as a two-factor factorial, with the first factor being dicamba rate, and the second being rice growth stage. There were no significant treatment effects observed for 100-seed weight, although dicamba rate played a significant role on the relative average panicle weight with a 15% and 39% reduction at the 1/10 and 1X rate, respectively. The same trend translated to reductions in both average number of seeds per panicle and grain yield, with a decrease of approximately 14% and 35%. An interaction was observed between dicamba rate and growth stage as well, with 1/10 and 1X rates of dicamba hastening rice maturity roughly 2 and 3 days, respectively. With severe consequences only being observed at high dicamba rates, the threat that off-target movement poses to rice is far less severe than what has been observed in soybean.

Introduction

With recent advancements in crop technology, growers may be provided the opportunity to effectively control problematic broadleaf weeds such as Palmer amaranth (*Amaranthus palmeri*) with new formulations of dicamba applied postemergence (POST) in dicamba-resistant (DR) crops. With such diverse crop production in the Mississippi Delta region of Arkansas, off-target movement of dicamba is a primary concern due to its mobility and visible injury to susceptible soybean varieties. From a visual standpoint, producers with non-DR soybean are impacted the most by dicamba volatility. However, given the ability of dicamba to elicit extensive landscape damage to soybean, the same landscape exposure seen in soybean may potentially be occurring in rice without any indication of visible injury especially as soybean herbicide applications overlap with reproductively growing rice. Several growth-regulating herbicides are labeled for weed control in Arkansas rice such as 2,4-D and quinclorac but have application cutoff dates due to late-season phytotoxicity (Scott et al., 2018). With dicamba having the same site of action as these herbicides, late-season drift events may pose a major concern for Arkansas rice production.

Procedures

Field experiments were conducted at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center near Stuttgart, Arkansas in the summer of 2018 and 2019. An inbred Clearfield cultivar was drill-seeded and kept weed free by utilizing typical Arkansas rice production practices and a standard rice weed control program respective to a Clearfield system. Hand-weeding was incorporated as needed.

Because we were interested in understanding the implications of off-target movement of dicamba on reproductive rice, the experimental structure was a two-factor factorial (dicamba concentration by growth stage) randomized complete block design with 4 replications. The Engenia formulation of dicamba was applied at three growth stages: late boot, panicle exertion, and anthesis at 1, 1/10, 1/100, and 1/1000X rates, with 1X being 227 g ae/ac dicamba. Following each application timing, ratings of crop injury were taken at 7, 14, 21, and 28 days after treatment (DAT) on a 0% to 100% scale, with 0% indicating no injury and 100% being crop death. In order to assess and quantify any adverse effect late-season exposures of dicamba may have on rice, maturity, grain yield, and several yield components were measured. Before harvest, a sample of 5 panicles per plot was clipped at the same length to assess the average weight of panicles. The same 5 panicles collected prior to harvest from each plot also served to measure the number of seeds per panicle. Yield data were collected at harvest.

Results and Discussion

At 21 DAT, when dicamba injury is optimal in soybean, a significant main effect was observed between visible injury and

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

[2] Assistant Professor/Extension Weed Scientist, Department of Crop, Soil and Environmental Sciences, Lonoke.

dicamba concentration independent of growth stage. Visible injury only occurred at the two highest rates, being 12% and 3% at the 1 and 1/10X rate respectively (Table 1). Although the two highest rates of dicamba caused relatively minor injury, injured plots visually appeared to have hastened rice maturity. An interaction was observed between dicamba rate and rice growth stage on relative maturity, which was determined when 50% of panicles within a plot were present. In comparison to the nontreated control, maturity was hastened approximately 2 and 3 days when rice was treated with a 1/10 and 1X rate of dicamba (Table 2).

However, visible injury data alone did not capture the extent of dicamba injury when evaluating grain yield and its components. Once again, regardless of growth stage, the rate of dicamba heavily influenced yield and decreased performance with minimal symptomology. Rice treated with a 1/100 or a 1/1000X rate of dicamba did not show a decrease in yield in comparison to the nontreated control, however, rice receiving a 1 or 1/10X rate of dicamba yielded significantly less, with yields as low as 57% and 79% of the nontreated control (200 bu./ac) (Table 1).

For average panicle weight, only one main-effect was documented in response to dicamba rate. Similar to yield, a decrease in panicle weight was observed at the 1 and 1/10X rate of dicamba, which equated to 61% and 85% of the nontreated control (3.55 g) (Table 1). The same trend translates to the average number of seeds per panicle when considering dicamba rate, with the only significant decreases in seed count caused by the 1 and 1/10X rates of dicamba (63% and 84%) relative to the nontreated control (148 seeds/panicle) (Table 1).

Practical Applications

For Arkansas rice producers in proximity to DR crops, there appears to be minimal risk associated with off-target movement of dicamba onto rice during reproductive development. Observing visible injury and yield loss to rice is unlikely to occur. The only scenario in which a significant reduction in yield could potentially occur is with late-season tank contamination with high concentrations of dicamba or a misapplication.

Acknowledgments

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

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Table 1. Combined injury (3 weeks after herbicide application), panicle weight (post-harvest), seeds per panicle (post-harvest), and grain yield of rice following four rates of dicamba averaged over growth stage from 2018 and 2019 near Stuttgart, Arkansas.

Treatment	Rate	Injury[a]	Panicle weight[a]	Seeds per panicle[a]	Yield[a]
	g ae/ac	% of nontreated			
Dicamba	227	12 a	60 c	63 c	57 c
Dicamba	22.7	3 b	84 b	84 b	79 b
Dicamba	2.27	0 c	102 a	102 a	101 a
Dicamba	0.227	0 c	105 a	105 a	104 a

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

Table 2. Interaction of dicamba rate and growth stage on rice maturity (50% heading) near Stuttgart, Arkansas from 2018 and 2019.

Growth Stage	Rate	Maturity[ab]
	g ae/ac	days
Late boot	227	-3.00 c
	22.7	-2.14 c
	2.27	0.43 ab
	0.227	1.15 a
Panicle exertion	227	-2.71 c
	22.7	-2.14 c
	2.27	0.43 ab
	0.227	0.01 b
Anthesis	227	-2.86 c
	22.7	-0.57 b
	2.27	0.01 b
	0.227	0.29 ab

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

[b] Maturity measured in days relative to the nontreated control.

Evaluation of Weed Control Programs in Furrow-Irrigated Rice

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

Abstract

Furrow-irrigated rice (*Oryza sativa* L.) has gained popularity over the last two years in Arkansas. The objective of this research was to determine the most effective herbicide program for season-long weed control in furrow-irrigated rice. Experiments were conducted at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station in Marianna, Arkansas during the 2019 growing season. Several herbicide programs were evaluated, all of which contained Command (clomazone) preemergence (PRE) alone and in combination with other herbicide modes of action, followed by two postemergence (POST) applications of various herbicide combinations. Results indicate that applications of Command plus Sharpen PRE may provide the best broad spectrum weed control when Palmer amaranth is present. Multiple residuals applied PRE increased grass control, however later applications of Clincher combinations provided the highest control of troublesome grasses such as goosegrass. Multiple applications of Loyant at 6 to 8 oz/ac or Stam plus Grandstand provided the best control of Palmer amaranth.

Introduction

In the 2018 growing season 7.7% of Arkansas rice acres utilized a furrow-irrigated system (Hardke, 2018). Weed management in the absence of a permanent flood will be more challenging to rice producers because of the increased presence of terrestrial weeds. Furthermore, prolonged moist conditions in furrows will extend the period of weed emergence during the growing season. Therefore, an effective weed management program for furrow-irrigated rice requires multiple herbicides which provide broad-spectrum, residual weed control (Norsworthy et al., 2008). With the widespread increase in furrow-irrigated rice acres, weed control programs and their effectiveness in this system have come under question. The purpose of this research was to determine the most effective herbicide program for season-long weed control in furrow-irrigated rice.

Procedures

A field experiment was conducted in 2019 at the University of Arkansas System Division Lon Mann Cotton Research Station in Marianna, Arkansas on a Calloway silt loam soil. Rice cultivar RT CLXL745 was planted on raised beds at 20 lb/ac and individual plots were 12.6 feet wide and 30 feet in length. The experimental design was a randomized complete block with 4 replications. Several herbicide programs were evaluated, all of which contained Command preemergence (PRE) alone and in combination with other herbicide modes of action, followed by two postemergence (POST) applications of various herbicide combinations (Table 1). An untreated check was included for weed control comparison. Applications were made at planting (PRE), 14 days after planting (Delay PRE), 4–5 lf rice (EPOST), and 2–3 leaf weeds (LPOST). All herbicide applications were made using a self-propelled sprayer calibrated to deliver 12 gal/ac at 3 mph with AIXR110015 spray nozzles.

Data collected consisted of visible weed efficacy ratings, which are defined as % control, where 0% was no control and 100% was complete control compared to the untreated check. Weed control ratings were recorded 28 days after planting (DAP) and 14 days after each application. Data were analyzed and subjected to analysis of variance and means were separated by Fisher's protected least significant difference at a *P*-value of 0.05.

Results and Discussion

Palmer amaranth control was highest 28 days after planting (DAP) when Sharpen (saflufenacil) 2 oz/ac (ounces/acre) was applied with Command PRE (Table 1). Palmer amaranth control POST was only achieved 14 days after LPOST with multiple applications or combinations of Loyant (florpyrauxifen-benzyl) applied at 6 to 8 oz/ac or with a tank mix combination of Stam M-4 (propanil) 96 oz/ac plus Grandstand (triclopyr) 8oz/ac. If Loyant is used in the LPOST application, data suggests that the rate should be increased to at least 8 oz/ac to account for larger pigweed escapes (Table 1). Results indicate, two applications of one of the previous two herbicide mixtures will be needed for season-long Palmer amaranth control in furrow-irrigated rice. Barnyardgrass (*Echinochloa crus-galli* L.) control was similar to management in a flooded rice environment; however, residuals become more important in a furrow-irrigated rice system (Table 2). Applications of Newpath (imazethapyr) early POST followed by either Clincher (cyhalofop), Ricestar (fenoxaprop) or Regiment (bispyribac-sodium) LPOST provided the highest control of barnyardgrass by 14 days LPOST. If POST applications were not made timely then barnyardgrass control was significantly reduced. Goosegrass (*Eleusine indica* L.) has proven to be difficult to control in furrow-irrigated rice fields. Goosegrass control was highest (87%) when Clincher 15 oz/ac was applied in a program LPOST (Table 3). One of the best herbicide programs across all

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[1] Program Associate, Professor, Professor, and Program Associate, respectively, Department of Crop, Soil, and Environmental Sciences, Lonoke.

[2] Program Associate and Program Associate, respectively, Southeast Research and Extension Center, Monticello.

weed species evaluated was Command plus Gambit PRE followed by RiceBeaux plus Rice One EPOST followed by Loyant plus Clincher LPOST.

Practical Applications

The weed spectrum appeared to shift more towards broadleaves and difficult-to-control grasses in the furrow-irrigated rice system. Producers should budget at least one extra herbicide application in furrow-irrigated rice production for difficult-to-control weeds and increased weed germination late season in absence of the flood. Additionally, multiple residual herbicide applications should be overlapped to prevent continuous flushes of grass weed species.

Acknowledgments

The authors would like to thank the Arkansas Rice Promotion Board and the University of Arkansas System Division of Agriculture for their support and funding this project.

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Table 1. Palmer amaranth control 28 days after planting (DAP) and 14 days after the late postemergence application (LPOST) in furrow-irrigated rice.

				% Palmer amaranth control	
At planting (PRE)	**Delay PRE[a]**	**Early POST[b]**	**Late POST (LPOST)[c]**	**28 DAP**	**14 LPOST[d]**
Command 17 oz/ac + Sharpen 2 oz/ac	-	Gambit 2 oz/ac + Newpath 6 oz/ac	Loyant 6 oz/ac	95.8	90.8
Command 21.3 oz/ac + League 6 oz/ac	-	RiceBeaux 3 qt/ac	Regiment 1 oz/ac + Newpath 6 oz/ac	88.5	89.5
Command 17 oz/ac	Prowl H_2O 32 oz/ac	RiceBeaux 3 qt/ac	Sharpen 1 oz/ac + Ricestar HT 24 oz/ac	83.3	66.3
Command 17 oz/ac + Sharpen 2 oz/ac	-	RiceBeaux 3 qt/ac	Newpath 6 oz/ac + Grandstand 8 oz/ac	94.5	89.8
Command 17 oz/ac + Sharpen 2 oz/ac	-	Prowl H_2O 32 oz/ac + RiceBeaux 3 qt/ac	Stam M-4 96 oz/ac + Grandstand 8 oz/ac	96.8	88.5
Command 17 oz/ac + Sharpen 2 oz/ac	-	Bolero 48 oz/ac + Ricestar 24 oz/ac + Prowl H_2O 1 qt/ac	Loyant 8 oz/ac	99	96.8
Command 12.5 oz/ac + Sharpen 2 oz/ac	-	RiceBeaux 3 qt/ac + RiceOne 40 oz/ac	Loyant 6 oz/ac	86.3	84
Command 12.8 oz/ac + Sharpen 2 oz/ac	-	Newpath 6 oz/ac + Facet L 32 oz/ac	Loyant 6 oz/ac	91	92.3
Command 17 oz/ac + Gambit 2 oz/ac	-	RiceBeaux 3 qt/ac + RiceOne 40 oz/ac	Loyant 6 oz/ac + Clincher 15 oz/ac	97	91
Command 17 oz/ac + Sharpen 2 oz/ac	-	Loyant 6 oz/ac + Regiment 0.5 oz/ac	Loyant 6 oz/ac + Newpath 6 oz/ac	95.8	95.5
LSD$_{0.05}$[e]				9.91	12.13

[a] Delayed preemergence (delay PRE) = 14 days after planting.

[b] Early postemergence (EPOST) = application made 40 days after planting.

[c] Late postemergence (LPOST) = application made 56 days after planting.

[d] 14 days after the late POST application.

[e] LSD = least significant difference.

Table 2. Barnyardgrass control 14 days after the early postemergence (EPOST) application and 14 days after the late postemergence application (LPOST) in furrow-irrigated rice.

At planting (PRE)	Delay PRE[a]	Early POST (EPOST)[b]	Late Post (LPOST)[c]	% Barnyardgrass Control 14 EPOST[d]	% Barnyardgrass Control 14 LPOST[e]
Command 17 oz/ac + Sharpen 2 oz/ac	-	Gambit 2 oz/ac + Newpath 6 oz/ac	Loyant 6 oz/ac	81.3	55
Command 21.3 oz/ac + League 6 oz/ac	-	RiceBeaux 3 qt/ac	Regiment 1 oz/ac + Newpath 6 oz/ac	22.5	68.9
Command 17 oz/ac	Prowl H_2O 32 oz/ac	RiceBeaux 3 qt/ac	Sharpen 1 oz/ac + Ricestar HT 24 oz/ac	27.5	67.5
Command 17 oz/ac + Sharpen 2 oz/ac	-	RiceBeaux 3 qt/ac	Newpath 6 oz/ac + Grandstand 8 oz/ac	60	72.5
Command 17 oz/ac + Sharpen 2 oz/ac	-	Prowl H_2O 32 oz/ac + RiceBeaux 3 qt/ac	Stam M-4 96 oz/ac + Grandstand 8 oz/ac	40	55
Command 17 oz/ac + Sharpen 2 oz/ac	-	Bolero 48 oz/ac + Ricestar 24 oz/ac + Prowl H_2O 1 qt/ac	Loyant 8 oz/ac	55	75
Command 12.5 oz/ac + Sharpen 2 oz/ac	-	RiceBeaux 3 qt/ac + RiceOne 40 oz/ac	Loyant 6 oz/ac	0	45
Command 12.8 oz/ac + Sharpen 2 oz/ac	-	Newpath 6 oz/ac + Facet L 32 oz/ac	Loyant 6 oz/ac	51.3	55
Command 17 oz/ac + Gambit 2 oz/ac	-	RiceBeaux 3 qt/ac + RiceOne 40 oz/ac	Loyant 6 oz/ac + Clincher 15 oz/ac	70	86.3
Command 17 oz/ac + Sharpen 2 oz/ac	-	Loyant 6 oz/ac + Regiment 0.5 oz/ac	Loyant 6 oz/ac + Newpath 6 oz/ac	81.3	82.5
$LSD_{0.05}$[f]				18.89	20.7

[a] Delayed preemergence (delay PRE) = 14 days after planting.

[b] Early postemergence (EPOST) = application made 40 days after planting.

[c] Late postemergence (LPOST) = application made 56 days after planting.

[d] Barnyardgrass control 14 days after the early post application.

[e] Barnyardgrass control 14 days after the late post application.

[f] LSD = least significant difference.

Table 3. Goosegrass control 14 days after the early postemergence (EPOST) application and 14 days after the late postemergence application (LPOST) in furrow-irrigated rice.

At planting (PRE)	Delay PRE[a]	Early POST (EPOST)[b]	Late Post (LPOST)[c]	% Goosegrass Control 14 EPOST[d]	 14 LPOST[e]
Command 17 oz/ac + Sharpen 2 oz/ac	-	Gambit 2 oz/ac + Newpath 6 oz/ac	Loyant 6 oz/ac	81.3	58.8
Command 21.3 oz/ac + League 6 oz/ac	-	RiceBeaux 3 qt/ac	Regiment 1 oz/ac + Newpath 6 oz/ac	71.3	82.5
Command 17 oz/ac	Prowl H_2O 32 oz/ac	RiceBeaux 3 qt/ac	Sharpen 1 oz/ac + Ricestar HT 24 oz/ac	64.8	72.5
Command 17 oz/ac + Sharpen 2 oz/ac	-	RiceBeaux 3 qt/ac	Newpath 6 oz/ac + Grandstand 8 oz/ac	82.5	78.8
Command 17 oz/ac + Sharpen 2 oz/ac	-	Prowl H_2O 32 oz/ac + RiceBeaux 3 qt/ac	Stam M-4 96 oz/ac + Grandstand 8 oz/ac	62.5	75
Command 17 oz/ac + Sharpen 2 oz/ac	-	Bolero 48 oz/ac + Ricestar 24 oz/ac + Prowl H_2O 1 qt/ac	Loyant 8 oz/ac	73.8	80
Command 12.5 oz/ac + Sharpen 2 oz/ac	-	RiceBeaux 3 qt/ac + RiceOne 40 oz/ac	Loyant 6 oz/ac	61.3	20
Command 12.8 oz/ac + Sharpen 2 oz/ac	-	Newpath 6 oz/ac + Facet L 32 oz/ac	Loyant 6 oz/ac	70	55
Command 17 oz/ac + Gambit 2 oz/ac	-	RiceBeaux 3 qt/ac + RiceOne 40 oz/ac	Loyant 6 oz/ac + Clincher 15 oz/ac	76.3	86.3
Command 17 oz/ac + Sharpen 2 oz/ac	-	Loyant 6 oz/ac + Regiment 0.5 oz/ac	Loyant 6 oz/ac + Newpath 6 oz/ac	84.8	82.5
$LSD_{0.05}$[f]				14.67	20.7

[a] Delayed preemergence (delay PRE) = 14 days after planting.

[b] Early postemergence (EPOST) = application made 40 days after planting.

[c] Late postemergence (LPOST) = application made 56 days after planting.

[d] Barnyardgrass control 14 days after the early post application.

[e] Barnyardgrass control 14 days after the late post application.

[f] LSD = least significant difference.

Control of Northern Jointvetch (*Aeschynomene virginica*) and Hemp Sesbania (*Sesbania herbacea*) Post-Flood Using Acetolactate Synthase-Inhibiting Herbicides and Benzobicyclon in Drill-Seeded Rice

B.M. Davis,[1] C.A. Sandoski,[2] L.T. Barber,[1] L.M. Collie,[1] and T.R. Butts[1]

Abstract

Benzobicyclon is a new herbicide with activity on a broad array of weed species that is soon to be available to rice (*Oryza sativa*) growers. It is an 4-hydroxyphenolpyruvate dioxygenase (HPPD)-inhibiting herbicide and when registered would be the first Group 27 herbicide labeled in Arkansas rice. Hemp sesbania (*Sesbania herbacea*) and northern jointvetch (*Aeschynomene virginica*) are very troublesome weeds in rice due to their black seed characteristics, and more options for post-flood control are needed. The objective of this research was to determine the effectiveness of benzobicyclon alone and in combination with acetolactate synthase (ALS)-inhibiting herbicides post-flood on controlling hemp sesbania and northern jointvetch. A field study was conducted in the summer of 2019 at the University of Arkansas at Pine Bluff Small Farm Outreach Center near Lonoke, Arkansas to evaluate tank-mixture options of ALS-inhibiting herbicides [halosulfuron (Permit) and halosulfuron + prosulfuron (Gambit)] at multiple rates with benzobicyclon for the control of hemp sesbania and northern jointvetch. Treatments consisted of benzobicyclon at 8.40 oz/ac applied alone and in combination with Permit at 1.00 and 1.33 oz/ac and Gambit at 0.50, 0.75, and 1.00 oz/ac. All treatments provided 85% or greater control of hemp sesbania and northern jointvetch at 4 weeks after treatment with the exception of benzobicyclon alone which provided less than 10% control of both weed species. At pre-harvest, hemp sesbania control remained above 85% for all treatments excluding the benzobicyclon alone treatment which was less than 30%. Benzobicyclon plus Permit at 1.00 and 1.33 oz/ac and benzobicyclon plus Gambit at 1.00 oz/ac provided greater than 80% control of northern jointvetch while the remainder of the treatments provided less than 70% control. Benzobicyclon alone showed no control of northern jointvetch at pre-harvest. Hemp sesbania and northern jointvetch were controlled post-flood using ALS-inhibiting herbicides. Although benzobicyclon provided minimal to no control of these weed species, mixtures with ALS-inhibiting herbicides still provided satisfactory control when using full, labeled rates.

Introduction

Benzobicyclon is a new herbicide with activity on a broad array of weed species that is soon to be available to rice (*Oryza sativa*) growers. It is an 4-hydroxyphenolpyruvate dioxygenase (HPPD)-inhibiting herbicide and when registered would be the first Group 27 herbicide labeled in Arkansas rice. Benzobicyclon is a pro-herbicide, meaning it must first be hydrolyzed to become an active herbicide. As a result, benzobicyclon is applied directly into the flood where it is hydrolyzed for root and shoot uptake (Gowan Company, 2018). Hemp sesbania (*Sesbania herbacea*) and northern jointvetch (*Aeschynomene virginica*) are very troublesome weeds in rice (Norsworthy et al., 2013), especially post-flood, due to their black seed characteristics. This “black seed” is difficult to separate from rice during harvest leading to weed seed in grain samples at the mill. This results in price dockages and reduces the probability of the rice crop for the farmer. More research is needed to determine susceptible weed species to benzobicyclon and more options for control of hemp sesbania and northern jointvetch post-flood are required. The objective of this research was to determine the effectiveness of benzobicyclon alone and in combination with acetolactate synthase (ALS)-inhibiting herbicides post-flood on controlling hemp sesbania and northern jointvetch.

Procedures

A field study was conducted in the summer of 2019 at the University of Arkansas at Pine Bluff Small Farm Outreach Center near Lonoke, Arkansas to evaluate tank-mixture options of ALS-inhibiting herbicides [halosulfuron (Permit) and halosulfuron + prosulfuron (Gambit)] at multiple rates with benzobicyclon for the control of hemp sesbania and northern jointvetch. Treatments consisted of benzobicyclon at 8.40 oz/ac applied alone and in combination with Permit at 1.00 and 1.33 oz/ac and Gambit at 0.50, 0.75, and 1.00 oz/ac. A nontreated control was also included for a total of 7 treatments. Plots were 10 × 25 ft in size and were drill seeded with Provisia rice at 90 lb/ac.

Experimental design was a randomized complete block with three replications. Treatments were applied post-flood with a CO_2 backpack sprayer equipped with DG 110015 tips

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[1] Program Associate, Professor-Extension Weed Scientist, Program Associate, and Assistant Professor-Extension Weed Scientist, respectively, Department of Crop, Soil, and Environmental Sciences, Lonoke.

[2] Product Development Representative, Gowan USA, Collierville, Tennessee.

calibrated to deliver 10 gal/ac. Applications were made three weeks following flood establishment, and weeds were between 24 and 36 inches tall. Visual weed control ratings were taken weekly and were estimated using a scale of 0% to 100% where: 0% is no control and 100% is complete plant death. 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

Results showed all treatments provided 85% or greater control of hemp sesbania and northern jointvetch at 4 weeks after treatment with the exception of benzobicyclon alone which provided less than 10% control of both weed species (Figs. 1 and 2). At the pre-harvest timing, hemp sesbania control remained above 85% for all treatments excluding the benzobicyclon alone treatment which was less than 30% (Fig. 2). Northern jointvetch control with benzobicyclon plus Permit at 1.00 and 1.33 oz/ac and benzobicyclon plus Gambit at 1.00 oz/ac provided greater than 80% control, while the remainder of the treatments provided less than 70% control (Fig. 1). Benzobicyclon alone showed no control of northern jointvetch at pre-harvest (Fig. 1). To achieve adequate northern jointvetch control late season when benzobicyclon is applied, full label rates of the ALS-inhibiting herbicides need to be applied in mixture. Weed size was also a critical factor in achieving adequate weed control. Previous research showed excellent post-flood control of hemp sesbania and northern jointvetch with ALS-inhibiting herbicides applied alone at reduced rates (Davis et al., 2020), but weeds in this study were two to three times greater in size compared to that research, thereby requiring greater use rates. Furthermore, other environmental factors such as flood depth and flood consistency may have affected overall weed control.

Practical Applications

Hemp sesbania and northern jointvetch were controlled post-flood using full label rates of ALS-inhibiting herbicides alone or in combination with benzobicyclon. This research highlights effective herbicide options for controlling these weeds in the event of weed escapes or a salvage situation to eliminate "black seed" from accumulating in rice samples. Weed size and timing of application are critical in the control of these problematic rice weeds in Arkansas. Both ALS-inhibiting herbicides (Permit and Gambit) evaluated in this research applied at full label rates in combination with benzobicyclon controlled these problematic weeds as a post-flood option in flooded rice. However, benzobicyclon alone did not control these weed species.

Acknowledgments

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

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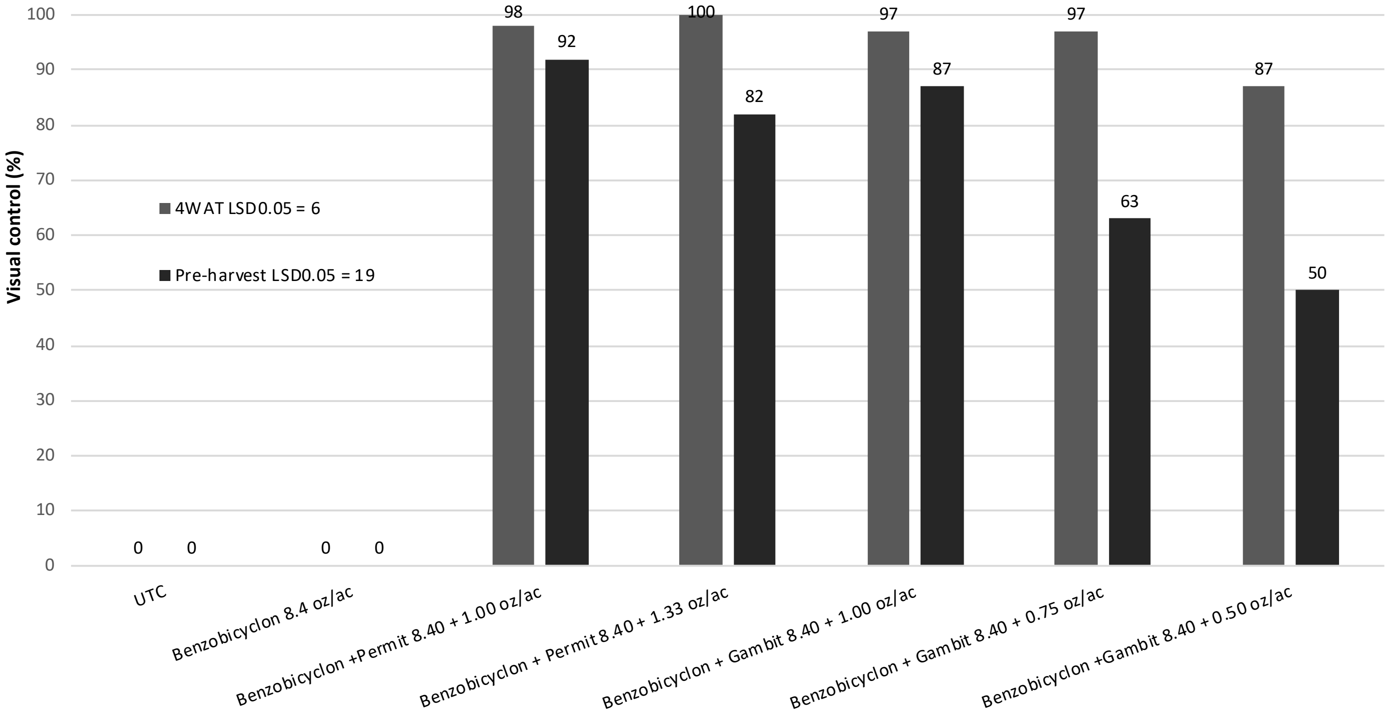

Fig. 1. Northern jointvetch control with acetolactate synthase (ALS)-inhibiting herbicides plus benzobicyclon at 4 weeks after treatment (WAT) and pre-harvest.

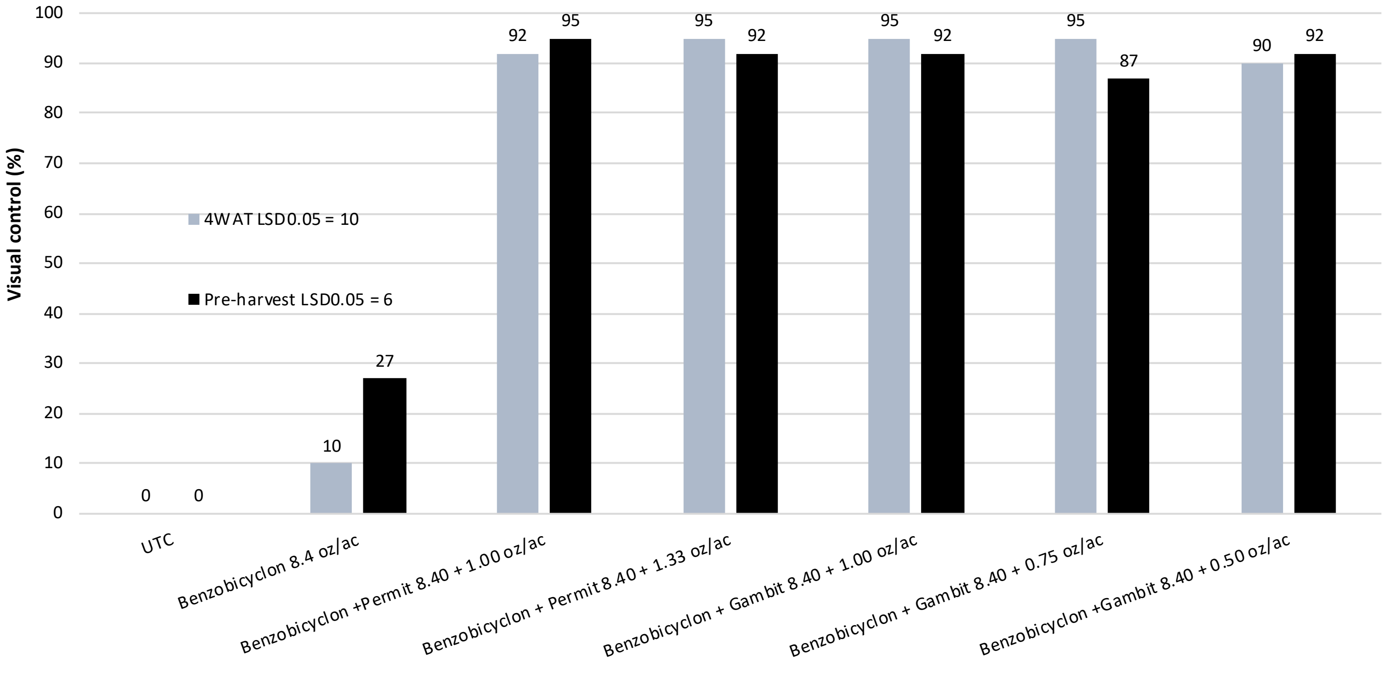

Fig. 2. Hemp sesbania control with acetolactate synthase (ALS)-inhibiting herbicides plus benzobicyclon at 4 weeks after treatment (WAT) and pre-harvest.

Salvage Options for Northern Jointvetch (*Aeschynomene virginica*) and Hemp Sesbania (*Sesbania herbacea*) Using Acetolactate Synthase-Inhibiting Herbicides in Drill-Seeded Rice

B.M. Davis,[1] C. A. Sandoski,[2] L. T. Barber,[1] L. M. Collie,[1] and T. R. Butts[1]

Abstract

Hemp sesbania (*Sesbania herbacea*) and northern jointvetch (*Aeschynomene virginica*) are among the top ten problematic rice (*Oryza sativa*) weeds in Arkansas. Several options are available for early-season control; but in the event of a failure or escape, there are few options for a post-flood salvage treatment that will provide adequate control. A field study was conducted in the summer of 2019 to evaluate halosulfuron (Permit), halosulfuron + thifensulfuron (Permit Plus), and halosulfuron + prosulfuron (Gambit) applied alone at multiple rates on hemp sesbania and northern jointvetch. Rates consisted of Permit at 0.33, 0.67, 1.00, and 1.33 oz/ac, Permit Plus at 0.38 and 0.75 oz/ac, and Gambit at 0.50, 1.00, 1.50, and 2.00 oz/ac. All treatments provided 100% control of both weed species at 3 weeks after treatment (WAT). At pre-harvest, all treatments still provided excellent control of greater than 94%. Permit and Gambit each applied at 1.00 oz/ac had the greatest numerical control (98%) of northern jointvetch at pre-harvest. The lowest labeled rates of the evaluated acetolactate synthase (ALS)-inhibiting herbicides would be advisable as they successfully controlled these weed species and would be more economical for the grower. For example, Permit at 0.33 oz/ac, Permit Plus at 0.38 oz/ac and Gambit at 0.50 oz/ac all controlled northern jointvetch and hemp sesbania over 95% at pre-harvest. Hemp sesbania and northern jointvetch were successfully controlled in a post-flood salvage situation using ALS-inhibiting herbicides alone.

Introduction

Hemp sesbania (*Sesbania herbacea*) and northern jointvetch (*Aeschynomene virginica*) are among the top ten problematic rice (*Oryza sativa*) weeds in Arkansas according to a crop consultant survey (Norsworthy et al., 2013). Both weeds produce "black seed" that is difficult to separate from rice during harvest leading to weed seed in grain samples at the mill. This results in price dockages and reduces the profitability of the rice crop for the farmer. Several options are available for early-season control of these weed species, but in the event of a failure or escape, there are few labeled options that would be recommended for a post-flood salvage treatment that will provide adequate control. The objective of this research was to determine a viable herbicide option to control hemp sesbania and northern jointvetch in a post-flood salvage situation.

Procedures

A field study was conducted in the summer of 2019 at the University of Arkansas at Pine Bluff Small Farm Outreach Center near Lonoke, Arkansas. The study evaluated efficacy of several acetolactate synthase (ALS)-inhibiting herbicides [halosulfuron (Permit), halosulfuron + thifensulfuron (Permit Plus), and halosulfuron + prosulfuron (Gambit)] applied alone at multiple rates on hemp sesbania and northern jointvetch. Treatments consisted of: Permit at 0.33, 0.67, 1.00, and 1.33 oz/ac, Permit Plus at 0.38 and 0.75 oz/ac, and Gambit at 0.50, 1.00, 1.50, and 2.00 oz/ac. A nontreated control was also included for a total of 11 treatments. Plots were 10 × 25 ft in size and were drill seeded with Provisia rice at 90 lb/ac.

Experimental design was a randomized complete block with four replications. Treatments were applied post-flood with a CO_2 backpack sprayer equipped with DG 110015 tips calibrated to deliver 10 gal/ac. Applications were made within one week following flood establishment, and weeds were between 6 and 14 inches tall. Visual weed control ratings were taken weekly and were estimated using a scale of 0% to 100% where: 0% is no control and 100% is complete plant death. 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

All treatments, regardless of active ingredient or rate used, provided 100% control of both weed species at 3 weeks after treatment (WAT) (Figs. 1 and 2). For example, Permit at 0.33 oz/ac and Permit at 1.33 oz/ac each controlled northern jointvetch and hemp sesbania 100% at 3 WAT. At pre-harvest, all treatments still provided excellent control of greater than 94% (Figs. 1 and 2). Permit and Gambit each applied at 1.00 oz/ac had the greatest numerical control (98%) of northern jointvetch at pre-harvest. This indicates regardless of the ALS-inhibiting herbicide active ingredient and rate used, excellent control of hemp sesbania and northern jointvetch in a post-flood salvage situation was achieved.

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[1] Program Associate, Professor-Extension Weed Scientist, Program Associate, Assistant Professor-Extension Weed Scientist, respectively, Department of Crop, Soil, and Environmental Sciences, Lonoke.

[2] Product Development Representative, Gowan USA, Collierville, Tennessee.

For example, Permit at 0.33 oz/ac, Permit Plus at 0.38 oz/ac, and Gambit at 0.50 oz/ac all controlled northern jointvetch and hemp sesbania over 95% at pre-harvest (Fig. 3). However, multiple environmental factors, such as weed size, flood depth, and flood consistency, may have contributed to this success. Although hemp sesbania and northern jointvetch were successfully controlled in a salvage situation in this research, it is still recommended to apply herbicides in a timely manner when weeds are small to achieve the most consistent and successful weed control.

Practical Applications

Hemp sesbania and northern jointvetch were successfully controlled in a post-flood salvage situation using ALS-inhibiting herbicides. Control of these weeds prior to seed set is key to reducing or eliminating “black seed” in samples at the mill and in return, reducing dockage to the grower to increase potential profit. Weed size and timing of application are critical in the control of these problematic rice weeds in Arkansas. Any of the three ALS-inhibiting herbicides evaluated in this research applied at label rates can control these problematic weeds as a salvage option in flooded rice. However, post-flood salvage treatments must be applied in accordance to product labels. Permit, Permit Plus, and Gambit all have a 48-day pre-harvest interval.

Acknowledgments

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

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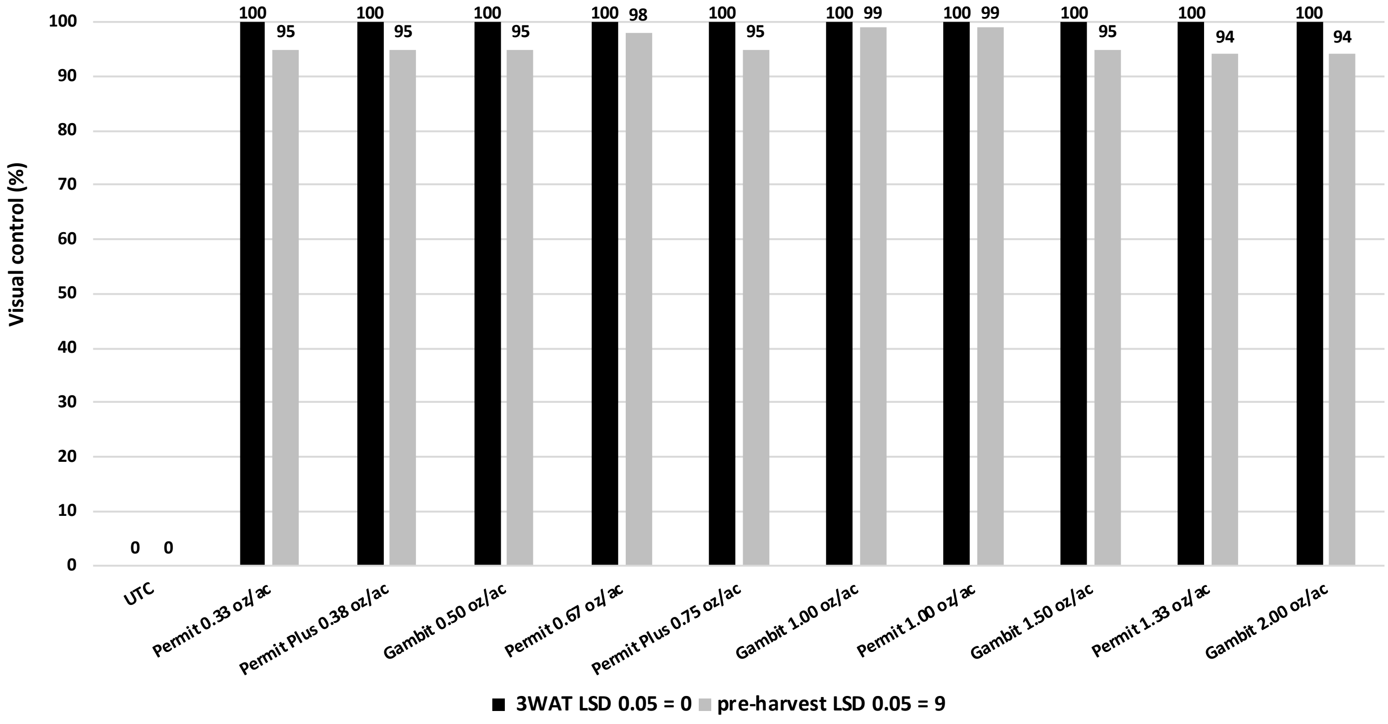

Fig. 1. Northern jointvetch control with acetolactate synthase (ALS)-inhibiting herbicides at 3 weeks after treatment (WAT) and preharvest. UTC = untreated check.

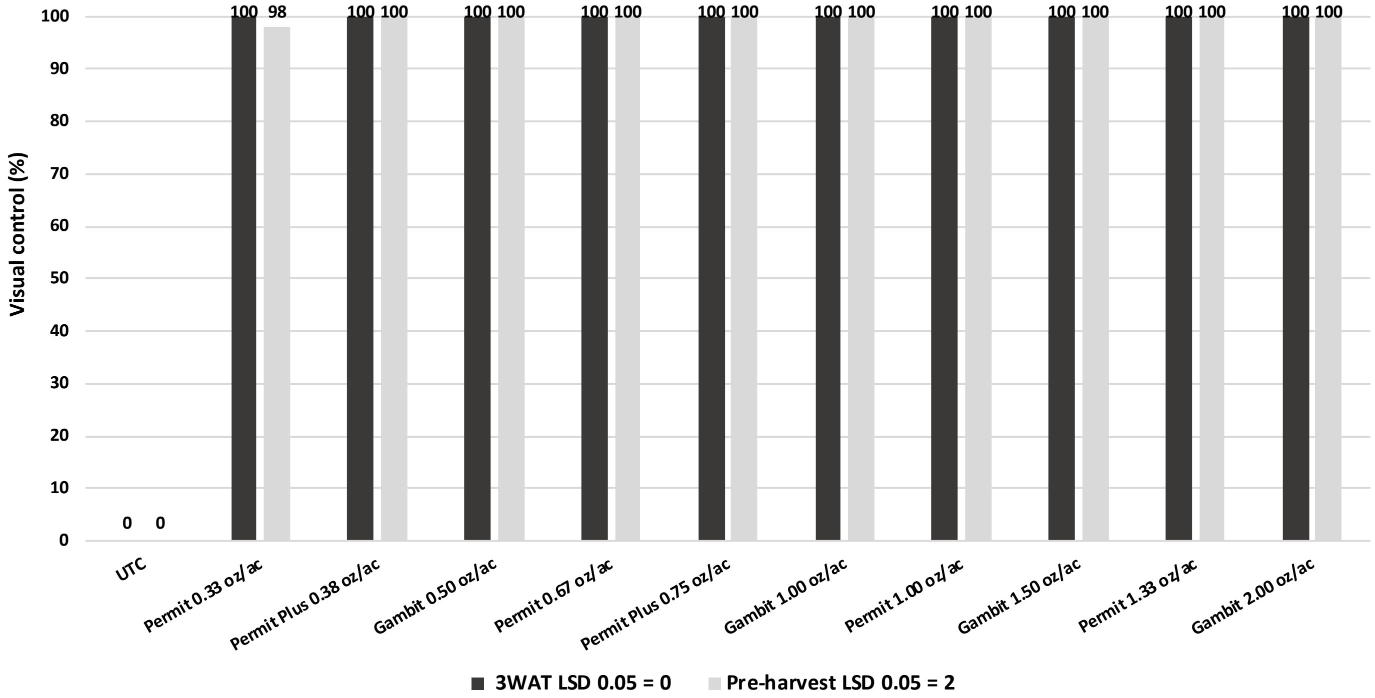

Fig. 2. Hemp sesbania control with acetolactate synthase (ALS)-inhibiting herbicides at 3 weeks after treatment (WAT) and pre-harvest. UTC = untreated check.

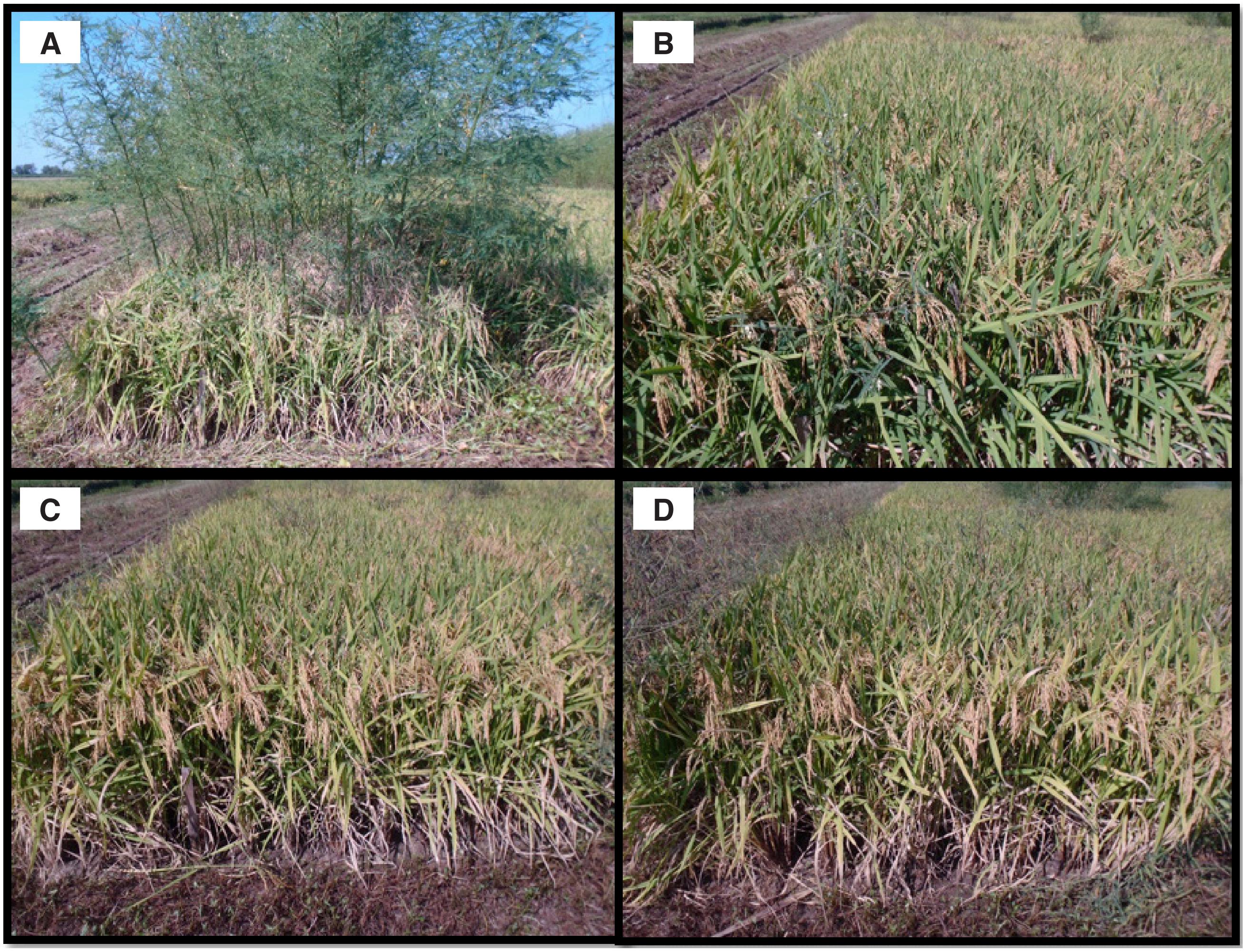

Fig. 3. Plot pictures at the pre-harvest timing of the nontreated control (A), Permit at 0.33 oz/ac (B), Permit Plus at 0.38 oz/ac (C), and Gambit at 0.50 oz/ac (D).

Tolerance of Rice Cultivars to Single and Sequential Loyant Applications

R.B. Farr,[1] J.K. Norsworthy,[1] J.W. Beesinger,[1] J.A. Patterson,[1] L.T. Barber,[1] and T.R. Butts[2]

Abstract

The commercial release of florpyrauxifen-benzyl, branded as Loyant, for use in rice production has been met with questions regarding the tolerance of rice cultivars to this herbicide. Field applications of Loyant have been shown to be occasionally injurious to rice, but research to document yield loss has been sparse. The purpose of this study was to determine the impact of single and sequential applications of Loyant on rice injury and grain yield. This study was conducted at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center near Stuttgart, Arkansas. The study was designed as a 5 × 4 factorial study with 5 different rice cultivars and 3 different application treatments with a nontreated check. Visual estimates of injury on a 0 to 100 scale were taken at 7, 14, 21, and 28 days after final treatment, days to 50% heading was recorded, and yield was collected at maturity. Results from this study indicate a significant difference in relative yield, maturity, and injury among herbicide treatments within some cultivars. Injury as high as 43% was observed on RT CLXL745 when sequential applications of Loyant were applied. Gemini and RT XP753 had comparable levels of injury following sequential applications, and injury to Diamond and Titan was less than that observed on the three hybrid cultivars. Rice grain yield was reduced 8% by sequential applications of Loyant, averaged over cultivars. Multiple applications of Loyant in drill-seeded, flooded rice production systems are not recommended because of the occurrence of greater injury with sequential applications than with a single application.

Introduction

With the continued evolution of herbicide resistance by weeds such as barnyardgrass and rice flatsedge in dry-seeded rice production systems (Heap, 2020), there is a continued need for effective herbicides that can be utilized. Corteva released a new herbicide, florpyrauxifen-benzyl, commercialized as Loyant in 2018. Florpyrauxifen-benzyl is a synthetic auxin herbicide in the arylpicolinate family that has herbicidal activity on broadleaf and a select few monocot weed species such as rice flatsedge and barnyardgrass (Hardke et al., 2019). Following the commercialization of florpyrauxifen-benzyl, concerns have arisen regarding the general crop safety of this compound as injury to rice began to be reported in the following summer (Hardke et al., 2019). Injury by florpyrauxifen-benzyl to rice can be expressed in several ways, primarily as either chlorosis of the leaves, twisting or turning of the flag-leaf, or as necrosis of tillers. It has been noted that injury can be inconsistent across environmental conditions and/or rice cultivars, but it does appear that florpyrauxifen benzyl is more injurious to long-grain hybrids compared to medium-grain varieties, according to cautions by the label (Anonymous, 2017). In other work, rice injury typically did not translate to yield loss when florpyrauxifen-benzyl was applied in sequential applications on long- and medium-grain varieties but yields were reduced for long-grain hybrid RT CLXL745 (Wright and Norsworthy, unpublished data). To better determine the effects of florpyrauxifen-benzyl on different cultivars, a study was conducted to determine which varieties would be more sensitive to the herbicide and to determine if sequential applications would be more injurious than single applications. Our hypothesis was that injury by florpyrauxifen-benzyl is dependent upon cultivar, rate, and number of applications.

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 the summer of 2019. This study was designed as a 5 × 4 factor factorial study with the first factor being cultivar and the second factor being application. For the first factor, 5 different cultivars were planted using an Almaco cone-drill at a rate of 22 seeds/ft for the 2 varieties and 10 seeds/ft for the 3 hybrids. The cultivars that were used for this study were Titan, Diamond, Gemini, RT CLXL745, and RT XP753. For the second factor, there were 4 separate herbicide programs evaluated: a nontreated control Loyant at 16 fl oz/ac applied to 2- to 3-leaf rice, Loyant at 32 fl oz/ac applied to 2- to 3-leaf rice, and Loyant at 16 fl oz/ac applied to 2- to 3-leaf rice followed by the same rate 14 days later. A nontreated was included for each cultivar. All applications were made at 15 gal/ac using a CO_2-pressurized backpack sprayer with AIXR 110015 nozzles. Plots were kept weed free throughout the season in order to prevent competition with weeds.

Data were collected in the form of visual injury ratings on a scale of 0 to 100, with 0 being no injury and 100 being crop

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

[2] Assistant Professor, Department of Crop, Soil, and Environmental Sciences, Lonoke.

death. These ratings were taken at 7, 14, 21, and 28 days after treatment (DAT). Days to 50% heading were recorded and yield was taken at harvest. Data were analyzed in JMP Pro 14.2 and means were subjected to analysis of variance using Fisher's least significant difference with α = 0.05.

Results and Discussion

There was a significant interaction between cultivar and treatment at 21 DAT. Injury levels varied among cultivars. For all cultivars at 21 DAT, Loyant at 16 fl oz/ac sequentially applied was the most injurious, with the cultivars Titan and Diamond having significantly less injury compared to the 3 hybrids (Table 1). The 16 and 2 fl oz/ac treatments were not significantly different from each other across all cultivars at 21 DAT. At 28 DAT, there was no interaction between cultivar and treatment, instead, only treatment was significant at this timing. Similarly to 21 DAT, the sequential Loyant application was most injurious to rice, causing 27% injury compared to 4% to 5% injury from a single application (Table 2). Injury to rice from Loyant did impact rice yield in some treatments. The cultivar RT XP753 had the lowest yield relative to the non-treated checks with only 79.5% relative yield. In terms of herbicide treatment, rice treated with sequential Loyant applications yielded 92% of their respective nontreated checks, averaged over cultivars (Table 2). This supports previous research suggesting that florpyrauxifen-benzyl injury as a result of sequential applications can result in yield reductions. This data also supports previous findings that hybrids are more sensitive to Loyant than medium- and long-grain varieties (Hardke et al., 2019; Wright, 2019).

Practical Applications

These findings provide important information for Arkansas rice producers who are wanting to utilize Loyant or florpyrauxifen-benzyl in their weed management programs. The findings from this study do support previous research and findings suggesting that hybrid cultivars are more sensitive than inbred cultivars, but found that yield reduction as a result is inconsistent and appears to be more cultivar specific. This information will help guide producers when determining which cultivars should be paired with florpyrauxifen-benzyl for weed management purposes. This study has also helped determine the relative injury and yield loss associated with different rates in order to generate best use practices for rice weed control. It was determined that sequential applications of florpyrauxifen-benzyl are detrimental to yield across several rice cultivars as a result of increased injury by multiple applications.

Acknowledgments

We would like to thank the University of Arkansas System Division of Agriculture, the Rice Research and Extension Center, and Corteva for their support in conducting this research.

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Table 1. Rice injury 21 days after treatment for herbicide treatment by cultivar interaction.

	Injury				
Treatment	**Gemini**	**Titan**	**Diamond**	**RT CLXL745**	**RT XP753**
(Loyant fl oz/ac)	----------------------	----------------------	%-------------	----------------------	----------------------
16	0.0 d†	4.5 d	3.8 d	1.3 d	8.8 cd
32	0.0 d	1.3 d	5.8 cd	4.0 d	3 d
16 fb 16	41.3 a	19.3 b	14.5 bc	42.5 a	34.5 a

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

Table 2. Rice injury 28 days after treatment and rough rice grain yield for herbicide treatment averaged over cultivar.

Treatment	Injury	Relative yield
(Loyant fl oz/ac)	**%**	**% of non-treated**
16	4.0 b†	95 ab†
32	5.0 b	102 a
16 fb 16	27.3 a	92 b

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

Response of Rice to Drift Rates of Glyphosate and Dicamba

O.W. France,[1] J.K. Norsworthy,[1] J.A. Patterson,[1] L.B. Piveta,[1] and T. Barber[2]

Abstract

Dicamba usage has increased with recent integration as a postemergence (POST) herbicide in dicamba-resistant crops, and its potential for off-target movement is well documented. Glyphosate, a commonly used herbicide in soybean, can be injurious to adjacently grown rice (*Oryza sativa* L.). This study was conducted to evaluate injury sustained by rice at simulated drift rates of dicamba and glyphosate at different application timings. Field experiments were conducted in 2018 and 2019 at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center near Stuttgart, Arkansas. A rice variety, CL 153, was planted and treated with dicamba, formulated as Clarity™, and glyphosate, formulated as Roundup PowerMax™, at a 1/20x, 1/80x, and 1/320x rate of dicamba and glyphosate as a mixture. Each rate of dicamba and glyphosate was applied at the one tiller, half-inch internode elongation, and boot growth stages. Injury and yield data were collected, and height data were collected for 2018 only. There was a difference in injury and yield between site year. For the 2018 trial, the highest rate of glyphosate + dicamba reduced rice yield at two of the three application timings. Injury never exceeded 6% on a 0–100% rating scale. For the 2019 trial, yield was decreased by the highest glyphosate + dicamba rate at the half-inch internode elongation stage. There was also an effect of injury at the highest rate of glyphosate + dicamba at the half-inch internode elongation application timing. This was the only timing to have injury above 3%. These results lead us to conclude that rice will need to be exposed to fairly high concentrations of glyphosate + dicamba for there to be risk for potential negative impact to the crop, albeit simulating true drift is difficult and field results may be slightly different than the methodology used to evaluate crop response in this trial.

Introduction

Until the release of dicamba-resistant crops, such as cotton and soybean, dicamba was commonly applied as an effective burndown application or in corn to control broadleaf weeds (Senseman, 2007). Recently integrated as a foliar postemergence (POST) herbicide for application in dicamba-resistant cotton and soybean, dicamba off-target movement, as physical drift or as volatility, has subsequently increased. The likeliness of other unintended applications of dicamba, such as spray-tank contamination applied into the growing season, has increased similarly. Although capable of injuring soybean at very low rates, dicamba is not known to damage to rice.

Glyphosate is a nonselective 5-enolpyruvyl-shikimate-3-phosphate (EPSP) synthase inhibitor used to control annual and perennial weeds in glyphosate-resistant crops (Senseman, 2007). Glyphosate is a highly applied chemical with physical drift potential and can be highly injurious to rice (Koger et al., 2005; Hensley et al., 2013). Considering the increasing occurrence of dicamba off-target movement since its integration as a POST herbicide, the possibility of drift events of both chemicals on rice is likely. While dicamba alone is not expected to be highly injurious to rice, in conjunction with glyphosate injury could be greater. The objective of this study was to evaluate injury sustained by rice when applied with low rates of dicamba and glyphosate in combination at different growth stages.

Procedures

Field experiments were conducted at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center near Stuttgart, Arkansas in the summer of 2018 and 2019. A rice variety, CL 153, was drilled into a tilled bed of plots measuring 6 × 17 feet and at a 0.5- to 1-inch depth. The experiment was a factorial design with four replications and a non-treated control for comparison. In 2018, Command 3ME was applied at planting and the trial was maintained weed free through applications of Superwham™ and Permit™. In 2019, Command 3ME was applied at planting and the trial was maintained weed free using applications of Facet, Gambit™, Ricebeaux™ and Ricestar™ as needed. At one tiller, half-inch internode elongation, and boot growth stages, respectively, the rice was sprayed with the following rates of Roundup PowerMax® and Clarity®, respectively: 0.8 and 0.4, 0.2 and 0.1, 0.05 and 0.025 oz acid equivalent (ae)/ac. These rates represent a 1/20x, 1/80x, and 1/320x respective rate of glyphosate and dicamba labeled for POST use on Xtend crops. No consecutive applications were made using multiple application timings for any treatment. Plots were rated for visible injury at 14 days after application. Heading dates were taken for each treatment and height per treatment was taken in the 2018 site year only. Harvest weight and moisture for each plot were also collected and used to calculate yield relative to the non-treated. All data were analyzed using analysis of variance in JMP 14.2 and means were separated using Fisher's protected least significant difference at $\alpha = 0.05$. Data were separated by year as there was a significant difference between trial years.

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[1] Graduate Assistant, Professor, Graduate Assistant, and Graduate Assistant, respectively, Department of Crop, Soil, and Environmental Science, Fayetteville.

[2] Professor, Department of Crop, Soil, and Environmental Sciences, Lonoke.

Results and Discussion

For the 2018 site year, low application rates resulted in no more than 6% injury to rice for any treatment (Table 1). Rice height was significantly influenced by the interaction of application rate and timing. The highest rate of glyphosate + dicamba consistently reduced rice height, with height reduction also observed for two of three timings at the middle rate of the glyphosate + dicamba mixture. The highest rate of glyphosate + dicamba reduced rice yield at two of the three application timings. Also, at the 1/20x application rate, relative yield was reduced numerically, but not statistically, by 26% compared to the nontreated check; whereas yield was reduced 4% at the 1/80x rate, and by 5% at the 1/320x rate. For the 2019 site year, rice was injured 25% more by the highest rate of glyphosate + dicamba at the half-inch internode elongation application timing than by any other treatment (Table 2). Injury at every application timing manifested as varying degrees of leaf malformation and chlorosis, especially at the two earlier application timings, and was less prominent at flag-leaf emergence following the half-inch internode elongation timing, which is consistent with data observed by Hensley et al. (2013) at a similar rate of glyphosate (Fig. 1). Injury symptomology following the second application timing was unique in that it manifested uniformly across plots as prominently bent secondary leaf blades whereas stems remained upright (Fig. 2). Injury at all other treatments did not exceed 3% with minimal symptomology of leaf malformation, curling, and chlorosis relative to the nontreated plots. Also, at the 1/20x application rate and at the half-inch internode elongation application timing, relative yield was significantly reduced by 31% compared to the nontreated check (Table 2).

Practical Applications

According to previous trials (Davis et al., 2011; Hensley et al., 2013), rice is most commonly injured by glyphosate when applied at early vegetative application timings and yield is most reduced when applied during reproductive growth stages. Data from the 2018 site year does not contradict literature; however, data collected from the 2019 site year indicate a possibility of greater injury and yield loss to an application near the half-inch internode elongation growth stage when dicamba and glyphosate were applied at simulated drift rates.

This research suggests that the impact of dicamba + glyphosate at low rates on rice could pose a risk to the crop if applied near the half-inch internode elongation stage, especially if the crop were in close proximity to the source of drift which would increase the likelihood of contact with a higher rate through off-target movement. It is acknowledged that these trials do not fully simulate drift because as spray droplets evaporate, the concentration of herbicide in the droplet increases likely increasing herbicide uptake and possible injury to the crop.

Acknowledgments

We would like to thank the Arkansas Rice Research and Promotion Board and the University of Arkansas System Division of Agriculture for support.

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Table 1. Influence of herbicide application stage and rate on rice height and relative yield of plots, 2018 site year.

Application Stage	Dicamba + Glyphosate Rate	Average Injury† 14 DAA	Height†‡	Relative Yield
	(lb ae/ac)		(in.)	% of nontreated
Nontreated	-	-	-	-
One tiller	28 + 56	6 a‡	33.63 a	62
One tiller	7 + 14	0 b	34.12 ab	84
One tiller	1.8 + 3.5	0 b	33.92 abc	89
Internode 0.5-in.	28 + 56	1 b	33.92 abc	100
Internode 0.5-in.	7 + 14	0 b	34.32 bc	105
Internode 0.5-in.	1.8 + 3.5	<1 b	34.42 bcd	105
Boot	28 + 56	0 b	33.99 cd	69
Boot	7 + 14	<1 b	34.09 cd	109
Boot	1.8 + 3.5	0 b	34.55 d	79

† No significant interaction was observed or plant height at 14 days after application (DAA) thus the significant main effect of application rate is shown.

‡ Means followed by the same letter within a column are not statistically different at α = 0.05 according to Fisher's protected least significant difference test.

Table 2. Influence of herbicide application stage and rate on rice height and relative yield of plots, 2019 site year.

Application Stage†	Dicamba + Glyphosate Rate	Average Injury‡ 14 DAA	Relative Yield‡
	(lb ae/ac)		% of nontreated
Nontreated	-	-	-
One tiller	28 + 56	2.25 b	90.42 a
One tiller	7 + 14	1.75 b	95.59 a
One tiller	1.8 + 3.5	<1 b	99.56 a
Internode 0.5-in.	28 + 56	25 a	69.00 b
Internode 0.5-in.	7 + 14	0 b	95.11 a
Internode 0.5-in.	1.8 + 3.5	0 b	106.19 a
Boot	28 + 56	<1 b	97.00 a
Boot	7 + 14	<1 b	102.75 a
Boot	1.8 + 3.5	0 b	101.54 a

† Significance within table separated by application timing as letter separation existed within application timing.

‡ Means followed by the same letter in a column are not statistically different at α = 0.05 according to Fisher's protected least significant difference test, data shown from 14 days after application (DAA).

Fig. 1. Image of leaf malformation observed in plots treated with the highest rate of glyphosate + dicamba at all application timings.

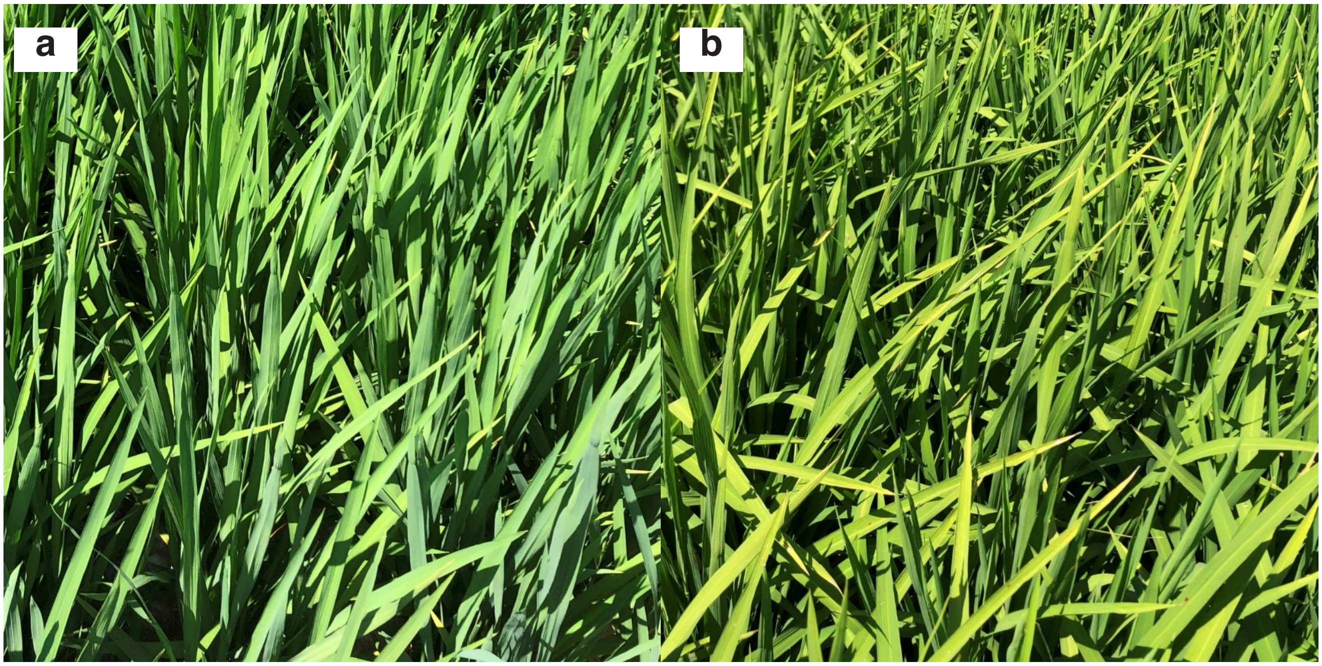

Fig. 2. (a) Image of nontreated plot versus (b) a plot treated with the highest rate of glyphosate + dicamba applied at the half-inch internode elongation application timing. Images were taken 14 days after the half-inch internode elongation application timing.

Comparison of Loyant and Graminicides Applied Alone and in Tank-Mixture in Arkansas

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

Abstract

Generally, Arkansas rice producers utilize multiple herbicides throughout the growing season to combat problematic weeds. An experiment was conducted on a silt loam soil in Tillar, Arkansas to evaluate the effectiveness of applying multiple rates of Loyant alone or in combination with commonly applied graminicides. At 20 days after treatment (DAT), Loyant 16 oz/ac + Clincher 31 oz/ac provided the most effective control of hemp sesbania, barnyardgrass, and rice flatsedge, with 99%, 98%, and 99% control, respectively. A positive trend was observed throughout the growing season as the rate of Loyant increased when applied alone or in tank-mixture with the graminicides. By 42 DAT, reduction in barnyardgrass control was observed from all treatments. It can be determined by these data that the most effective combination to control the present weeds is Loyant at 16 oz/ac + Clincher at 31 oz/ac. Regardless of the graminicide, these data suggest that applying Loyant at 16 oz/ac aided in controlling the weeds commonly found in Arkansas rice.

Introduction

In Arkansas rice production, multiple herbicides are used either alone or in combination to combat problematic weeds, in addition to reducing the development of herbicide-resistance. Typically, producers utilize graminicides, such as Clincher (cyhalofop) and Ricestar (fenoxaprop) to control the grass species commonly found in rice; however, it is found to be more beneficial to include multiple herbicides in a tank mixture to achieve a broad spectrum of control. Loyant™ (florpyrauxifen), a new herbicide that contains the Rinskor™ active has been shown to have broad-spectrum postemergence activity on most broadleaf and some grass, and sedge species (Hill et al., 2017 and Miller et al., 2016).

Procedures

In this experiment, multiple rates of Loyant were applied alone and in tank-mixture with graminicides to determine the most effective combination for the weeds present. This experiment was conducted on a silt loam soil in Tillar, Arkansas, with a texture of 18% sand, 56% silt, and 26% clay. Gemini rice cultivar was drilled at 30 lb/ac, with a plot size of 6.33 by 28 feet. The study was designed as a randomized complete block design with 4 replications, where herbicide efficacy was evaluated for the control of barnyardgrass (*Echinochloa crus-galli* L.), hemp sesbania (*Sesbania herbacea* (Mill.) McVaugh), and rice flatsedge (*Cyperus iria* L.). Treatments in this experiment consisted of Command at 12.5 oz/ac applied preemergence followed by Loyant applied alone at 6, 8 and 16 oz/ac; Clincher alone at 15.5 and 31 oz/ac; Ricestar alone at 24 oz/ac; Provisia (not labeled for the variety Gemini) alone at 15.5 oz/ac; as well as each of the graminicides at their respective rates in tank-mixture with the 3 rates of Loyant. These treatments were applied early postemergence when the rice was at the 3- to 4-leaf stages and barnyardgrass at the 4- to 5-leaf stages. Herbicide treatments were applied with a tractor mounted sprayer calibrated to deliver 12 gal/ac at 3 mph with TeeJet AIXR110015 nozzles.

Results and Discussion

Regardless of the evaluation timing, a positive trend was observed as the rate of Loyant increased when applied alone or in tank-mixture with the graminicides. At 20 days after treatment (DAT), >90% control of barnyardgrass was observed from several treatments, with Loyant at 16 oz/ac + Clincher at 31 oz/ac providing the most effective control at this timing (Table 1). All treatments containing Loyant provided effective control of hemp sesbania throughout the season. Greater than 95% control of rice flatsedge was observed from most treatments, except where lower rates of Loyant were tank-mixed with Provisia and Clincher. It was evident that in the treatments containing Provisia, greater rates of Loyant were required to control the increased population of rice flatsedge where the crop stand had been killed. Although a reduction in barnyardgrass control was observed from all treatments at 42 DAT, the same positive trend was observed as the Loyant rate increased (Table 2). The combinations of Loyant at 8 and 16 oz/ac with both rates of Clincher, Ricestar at 24 oz/ac, and Provisia at 15.5 oz/ac provided comparable control of barnyardgrass with ≥80%. Greater than 95% control of rice flatsedge was continued to be observed at this evaluation timing, except from the Loyant at 6 oz/ac + Provisia at 15.5 oz/ac treatment.

Practical Applications

Based on these data, it can be determined that the most effective combination to control the present weeds is Loyant at 16 oz/ac + Clincher at 31 oz/ac. Additionally, Loyant at 16 oz/

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[1] Program Associate and Program Associate, Department of Crop, Soil, and Environmental Sciences, Monticello.

[2] Professor, Program Associate, and Program Associate, respectively, Department of Crop, Soil, and Environmental Sciences, Lonoke.

ac + Ricestar at 24 oz/ac provided comparable control of both species throughout the growing season. Regardless of the graminicide applied, these data suggest that applying the higher rate of Loyant aided in controlling these problematic weeds found in Arkansas rice.

Acknowledgments

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

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Table 1. Hemp sesbania, barnyardgrass, and rice flatsedge control at 20 days after the early postemergence application.

Program[a]	Rate(s)	Application Timing	Hemp sesbania	Barnyardgrass	Rice flatsedge
	oz/ac		----------------------------	% control	------------------------------
Nontreated Control	----	----	0	0	0
Loyant	6	EPOST[b]	99	66	95
Loyant	8	EPOST	99	76	95
Loyant	16	EPOST	99	92	99
Clincher	15.5	EPOST	0	46	0
Clincher	31	EPOST	0	63	0
Ricestar	24	EPOST	0	46	0
Provisia	15.5	EPOST	0	87	0
Loyant + Clincher	6 + 15.5	EPOST	99	74	89
Loyant + Clincher	6 + 31	EPOST	99	91	83
Loyant + Clincher	8 + 15.5	EPOST	99	83	97
Loyant + Clincher	8 + 31	EPOST	99	92	95
Loyant + Clincher	16 + 15.5	EPOST	99	86	97
Loyant + Clincher	16 + 31	EPOST	99	98	99
Loyant + Ricestar	6 + 24	EPOST	99	60	92
Loyant + Ricestar	8 + 24	EPOST	99	52	95
Loyant + Ricestar	16 + 24	EPOST	99	91	99
Loyant + Provisia	6 + 15.5	EPOST	99	95	58
Loyant + Provisia	8 + 15.5	EPOST	99	88	90
Loyant + Provisia	16 + 15.5	EPOST	99	83	94
LSD (*P* = 0.05)			1.0	24	15

[a] All treatments included Command at 12.5 ounces per acre applied preemergence.

[b] Abbreviations: early postemergence (EPOST); least significant difference (LSD); ounces (oz).

Table 2. Hemp sesbania, barnyardgrass, and rice flatsedge control at 42 days after the early postemergence application.

Program[a]	Rate(s)	Application Timing	Hemp sesbania	Barnyardgrass	Rice flatsedge
	oz/ac		-----------------------------	% control	-------------------------------
Nontreated Control	----	----	0	0	0
Loyant	6	EPOST[b]	99	54	99
Loyant	8	EPOST	99	68	99
Loyant	16	EPOST	99	74	99
Clincher	15.5	EPOST	0	53	0
Clincher	31	EPOST	0	76	0
Ricestar	24	EPOST	0	44	0
Provisia	15.5	EPOST	0	67	0
Loyant + Clincher	6 + 15.5	EPOST	99	59	99
Loyant + Clincher	6 + 31	EPOST	99	82	96
Loyant + Clincher	8 + 15.5	EPOST	99	75	99
Loyant + Clincher	8 + 31	EPOST	99	81	97
Loyant + Clincher	16 + 15.5	EPOST	99	83	99
Loyant + Clincher	16 + 31	EPOST	99	85	99
Loyant + Ricestar	6 + 24	EPOST	99	53	99
Loyant + Ricestar	8 + 24	EPOST	99	51	97
Loyant + Ricestar	16 + 24	EPOST	99	87	99
Loyant + Provisia	6 + 15.5	EPOST	99	83	77
Loyant + Provisia	8 + 15.5	EPOST	99	83	93
Loyant + Provisia	16 + 15.5	EPOST	99	81	97
LSD ($P = 0.05$)			1.0	12	9

[a] All treatments included Command at 12.5 ounces per acre applied preemergence.

[b] Abbreviations: early postemergence (EPOST); least significant difference (LSD); ounces (oz).

Evaluating the Utility of Benzobicyclon for Weedy Rice Control in Provisia Rice

J.A. Patterson,[1] J.K. Norsworthy,[2] J.W. Beesinger,[1] O.W. France,[1] and L.B. Piveta[1]

Abstract

Weedy rice (*Oryza sativa*) is particularly difficult to control in mid-South rice cropping systems due to its highly competitive and resilient nature, similarity to cultivated rice, and resistance to herbicides. Hence, there is a need for new effective sites of action in mid-South rice production. Gowan Company is actively pursuing registration of benzobicyclon, a Group 27 herbicide, as a post-flood option in rice. It will be the first 4-hydroxyphenylpyruvate dioxygenase-inhibiting (HPPD) herbicide commercially available in mid-South rice production. In 2019, two field experiments were conducted at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center near Stuttgart, Arkansas, and the Pine Tree Research Station near Colt, Arkansas. The experiments were implemented as randomized complete block designs with four replications. The objective of the experiments was to evaluate benzobicyclon-containing weedy rice control programs, most of which contain Provisia™ herbicide, in mid-South rice compared to a sequential two-application Provisia alone program. The herbicides used in the experiments included Prowl H_20 (pendimethalin), Bolero (thiobencarb), Warrant (acetochlor), Provisia (quizalofop), and Rogue (benzobicyclon). The herbicides were applied in various combinations and timings, except all benzobicyclon applications were made post-flood. At Stuttgart, four weeks after the post-flood application, >90% weedy rice control was observed for all treatments but was not significantly different. At four weeks after the post-flood application, ≤10% injury was observed from all treatments containing quizalofop followed by a post-flood application of benzobicyclon. At Pine Tree, four weeks after the post-flood application, >98% weedy rice control was observed for all programs containing quizalofop followed benzobicyclon. At four weeks after the post-flood application, no more than 4% injury was observed from all treatments containing quizalofop followed by benzobicyclon. Findings from these experiments show that the use of benzobicyclon in Provisia rice systems could be a viable weedy rice control option and may provide some protection against weedy rice evolving resistance to Provisia herbicide.

Introduction

Weedy rice is the third-most problematic weed in mid-South rice production behind barnyardgrass (*Echinochloa crus-galli*) and sprangletop (*Leptochloa* spp.) (Norsworthy et al., 2013). Weedy rice has long been one of the most damaging weeds in direct-seeded rice cropping systems (Burgos et al., 2014) and can cause up to 80% yield loss and reduction of grain quality (Shivrain et al., 2010). Postemergence options for controlling weedy rice are limited because weedy rice is the same species as cultivated rice, making it difficult to control without also damaging the crop (Burgos et al., 2014). Benzobicyclon is a new rice herbicide actively being evaluated for use as a post-flood option to control mid-South rice weeds, including weedy rice. Benzobicyclon controls a broad spectrum of aquatics, broadleaves, grasses, and sedges, including those currently resistant to Group 2 (ALS) herbicides (Young, 2017). Benzobicyclon is a pro-herbicide, therefore it does not directly inhibit 4-hydroxyphenylpyruvate dioxygenase (HPPD) enzymes in plants (Komatsubara et al., 2009). Rather, benzobicyclon must undergo a hydrolysis reaction in the presence of water to be converted to the potent and phytotoxic compound benzobicyclon hydrolysate. Hence, it is imperative for growers to maintain a continuous flood throughout the growing season for benzobicyclon to perform optimally (Young, 2017).

Procedures

In the summer of 2019, a field experiment was conducted at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center near Stuttgart, Arkansas, and at the Pine Tree Research Station near Colt, Arkansas to evaluate benzobicyclon-containing weedy rice control programs, most of which contain Provisia™ herbicide, in the mid-South compared to currently used programs. At both locations, Provisia rice (PVL01) was planted at a 0.75-inch depth at a seeding rate of 22 seeds per row foot. One treatment contained a sequential application of Provisia (quizalofop) at the 3-leaf rice stage followed by an additional application of Provisia pre-flood, which is a standard Provisia herbicide program. Another treatment included sequential applications of Provisia at the 3-leaf stage and at pre-flood, then was followed by a post-flood application of benzobicyclon (Rogue). Two treatments contained a single application of Provisia at the 3-leaf stage or pre-flood, then were both followed by Rogue post-flood. The last treatment contained Prowl H_20 (pendimethalin) and Bolero (thiobencarb) delayed preemergence (DPRE) followed by sequential applications of Warrant (acetochlor) at the 1-leaf and 3-leaf stages followed by Rogue post-flood. Provisia was applied at 15.5 fl oz/ac across all Provisia-containing treatments. Rogue was applied at 12.6 fl oz/ac across all benzobicyclon-containing treatments. Applications

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

[2] Distinguished Professor, Department of Crop, Soil, and Environmental Sciences, Fayetteville.

were made using a CO_2-pressurized backpack sprayer calibrated to deliver 15 gal/ac at a 3-mph walking speed.

Data collected consisted of visible weedy rice control, visible crop injury, and yield. Visible weedy rice control and injury ratings were taken at 1, 2, 3, and 4 weeks after the post-flood application. Treatments were rated on a 0 to 100 scale, with 0 being no weed control or injury and 100 being complete weed control or crop death. Plots were harvested for yield using a small-plot combine, and rough rice grain yield was adjusted to 12% moisture. All data were analyzed and subjected to analysis of variance, and locations were analyzed separately due to site year having a significant main effect. All means were separated using Fisher's protected least significant difference ($\alpha = 0.05$).

Results and Discussion

At Stuttgart, four weeks after the post-flood application, >90% weedy rice control was observed for all treatments but was not significantly different (Table 1). At four weeks after the post-flood application, ≤10% injury was observed from treatments containing quizalofop followed by benzobicyclon (Table 2). Warrant-containing treatments severely injured rice at levels upwards of 40% (Table 2). Injury from Warrant can be attributed to sequential Warrant applications injuring the rice, then the post-flood application of Rogue exacerbated high levels of injury. Treatments containing Provisia followed by Rogue yielded ~20 bu./ac higher than treatments containing Provisia followed by Provisia (Table 2), likely because Provisia herbicide is a graminicide and did not control non-grass weeds which competed with the rice. Treatments containing Warrant yielded ~20 bu./ac less than treatments containing Provisia followed by Rogue (Table 2) due to the high levels of injury from Warrant affecting rice growth and maturity.

At Pine Tree, four weeks after the post-flood application, >98% weedy rice control was observed for all programs containing quizalofop followed by a post-flood application of benzobicyclon (Table 1). At four weeks after the post-flood application, no more than 4% injury was observed from treatments containing quizalofop followed by benzobicyclon (Table 2). Warrant-containing treatments injured rice at levels upwards of 20% (Table 2). At Pine Tree, there was no significant difference in yield between treatments (Table 2), likely due to weed density being less than what was present at Stuttgart.

Practical Applications

Rogue, or benzobicyclon, is a new herbicide site of action for rice growers in the mid-South. The use of benzobicyclon will enable growers to effectively control weedy rice, especially in Provisia Rice systems. Additionally, the use of benzobicyclon in Provisia systems may provide some protection against weedy rice evolving resistance to Provisia herbicide. Furthermore, the addition of benzobicyclon into current mid-South rice herbicide programs will provide growers with a non-traited, post-flood weedy rice control option.

Acknowledgments

Funding for this research was provided by the Arkansas Rice Research and Promotion Board and Gowan Company. Support also provided by the University of Arkansas System Division of Agriculture.

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Table 1. Visible weedy rice control 28 days after the post-flood application of Rogue at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center near Stuttgart, Arkansas, and the Pine Tree Research Station near Colt, Arkansas.

Herbicide program (application timing)	Weedy rice control 28 DAT[†] Stuttgart	Pine Tree
	--------%--------	
Provisia (3-lf) fb[‡] Provisia (pre-flood)	98	99 a[§]
Provisia (3-lf) fb Provisia (pre-flood) fb Rogue (post-flood)	98	99 a
Provisia (3-lf) fb Rogue (post-flood)	92	99 a
Provisia (pre-flood) fb Rogue (post-flood)	98	99 a
Prowl H_20 + Bolero (delayed preemergence) fb Warrant (1-lf) fb Warrant (3-lf) fb Rogue (post-flood)	94	50 b

[†] days after treatment (DAT).

[‡] fb = followed by.

[§] Letters within a column are used to separate means. Data with the same letters are not significantly different.

Table 2. Injury on Provisia rice 28 days after the post-flood application of Rogue and rough rice grain yield in experiments at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center near Stuttgart, Arkansas, and the Pine Tree Research Station near Colt, Arkansas.

	Stuttgart		Pine Tree	
Herbicide program (application timing)	Injury	Yield	Injury	Yield
	%	bu./ac	%	bu./ac
Nontreated	--	98 c	--	96
Provisia (3-lf) fb[†] Provisia (pre-flood)	3 b[‡]	117 b	0 b	93
Provisia (3-lf) fb Provisia (pre-flood) fb Rogue (post-flood)	10 b	146 a	4 b	92
Provisia (3-lf) fb Rogue (post-flood)	0 b	149 a	1 b	88
Provisia (pre-flood) fb Rogue (post-flood)	0 b	148 a	0 b	89
Prowl H_20 + Bolero (delayed preemergence) fb Warrant (1-lf) fb Warrant (3-lf) fb Rogue (post-flood)	40 a	126 b	20 a	96

[†] fb = followed by.

[‡] Letters within a column are used to separate means. Data with the same letters are not significantly different.

Do Barnyardgrass Accessions Differ in Sensitivity to Loyant?

G.L. Priess,[1] J.K. Norsworthy,[2] and C.B. Brabham[3]

Abstract

The commercialization and widespread use of Loyant® (florpyrauxifen-benzyl) for barnyardgrass control in Arkansas rice were observed in 2018. However, barnyardgrass accessions appeared to have different sensitivity levels to Loyant. Barnyardgrass seed from fields where plants survived Loyant applied the previous year were sent to the University of Arkansas System Division of Agriculture's Agricultural Experiment Station for accessions to be screened for sensitivity to the herbicide. A dose-response greenhouse experiment was designed to evaluate the effectiveness of Loyant on barnyardgrass at 1/16x, 1/8x, 1/4x, 1/2x, 1x, 2x, and 4x the labeled rate of 12.14 g acid equivalent (ae)/ac. The 1/4x rate of Loyant controlled the susceptible standard (100%). When a 2x rate of Loyant was applied, 8 out of 12 barnyardgrass accessions were controlled by less than 50%. Additionally, three commercial rice cultivars were evaluated for sensitivity to Loyant. Several of the evaluated barnyardgrass accessions exhibited similar sensitivity to Loyant when compared to the rice cultivars. Based on comparison to the susceptible standard, some accessions of barnyardgrass in Arkansas display a reduced sensitivity to Loyant. Future efforts should try to identify the mechanism for reduced sensitivity and determine if measures can be taken to effectively control this weed in fields where few chemical options remain.

Introduction

Weeds compete with rice throughout the growing season and cause economic losses from reduced grain yields and grain devaluation after harvest (Norsworthy et al., 2012). Rice consultants considered barnyardgrass (*Echinochloa crus-galli* L. Beauv.) as one of the most troublesome weeds in rice production due to the limited number of herbicide options to control herbicide-resistant biotypes (Norsworthy et al., 2013). To effectively combat herbicide-resistant barnyardgrass populations and for general rice weed control, Corteva™ Agriscience developed Loyant™ herbicide as a new postemergence option for the control of barnyardgrass in rice production systems.

Florpyrauxifen-benzyl is the active ingredient in Loyant™ and is classified as a synthetic auxin herbicide (WSSA Group 4). Historically, synthetic auxin herbicides (WSSA Group 4), such as Facet (quinclorac), have been used to control barnyardgrass in mid-South rice production systems, but resistance to quinclorac has been confirmed (Heap, 2020). The Loyant™ label states that quinclorac resistance does not confer resistance to florpyrauxifen-benzyl (Anonymous, 2017). Miller et al. (2018) displayed that 12.14 g ae/ac of florpyrauxifen-benzyl provided greater than 90% control of 152 barnyardgrass accessions from Arkansas. Some of the accession screened were quinclorac-resistant, thus providing validity to the prior statement from the label. However, after the commercial launch and widespread use of Loyant™ in 2018, many complaints were filed regarding the efficacy of Loyant™ for barnyardgrass control. Thus, raising the question, do barnyardgrass accessions differ in sensitivity to Loyant™.

Procedures

In the summer of 2018 following the launch and widespread use of florpyrauxifen-benzyl, many instances of barnyardgrass escapes were reported. Barnyardgrass seed was collected from troublesome fields and placed in 0 °C cold storage to break dormancy. Barnyardgrass accessions were chosen for a dose-response study based on prior florpyrauxifen-benzyl screenings. A susceptible standard was also predetermined and included in a dose-response screening of five troublesome barnyardgrass accessions and three rice cultivars. The rice cultivars chosen were Diamond, RT CLXL745, and Jupiter. Data collected on the three rice cultivars were pooled due to similar results among cultivars. Barnyardgrass accessions and rice cultivars were treated with six rates of florpyrauxifen-benzyl. The rates used varied by accession and rice cultivar tolerance. Rates used are displayed in Table 1. Barnyardgrass was planted into 7.6-cm pots filled with field soil comprised of a Leaf silt loam (fine, mixed, active, thermic Typic, Albaquults) with 34% sand, 53% silt, 13% clay, 1.5% organic matter, and a pH of 6.8. Barnyardgrass plants were thinned to three plants per pot following emergence. Applications of florpyrauxifen-benzyl + methylated seed oil (MSO) at 0.24 L/ac were made to 4- to 5-leaf barnyardgrass and rice, and all applications were made using a compressed air spray chamber delivering 20 gal/ac at 1 mph. A simulated flood was initiated 24 hours after application, and the flood was sustained throughout all evaluations. Barnyardgrass control ratings were collected at 14 and 35 days after treatment (DAT).

The data collected were fit with a least square regression curve by accession, and rice cultivars were pooled. Data were

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[1] Graduate Research Assistant, Department of Crop, Soil and Environmental Sciences, Fayetteville.

[2] Distinguished Professor, Department of Crop, Soil, and Environmental Sciences, Fayetteville.

[3] Post Doctoral Fellow, Department of Crop, Soil, and Environmental Sciences, Fayetteville.

analyzed using JMP 14.2 Pro (SAS Institute Inc., Cary, N.C.) and subjected to analysis of variance. Analyses were conducted by rate with the single factor being barnyardgrass accession. Means were separated using Fisher's protected least significant difference (α = 0.05).

Results and Discussion

The 1x rate (12.14 g ae/ac) of florpyrauxifen-benzyl controlled 4 out of 5 barnyardgrass accessions less than 50% (Table 1, Fig. 1). The 1x rate of florpyrauxifen-benzyl controlled accessions #73 and #92, 36%, and 91%, respectively (Table 1). Thus, differing sensitivity levels among barnyardgrass accessions were observed. At a 1/2x rate of florpyrauxifen-benzyl, accession #73 and the three rice cultivars did not differ in levels of control. Therefore, it is unlikely that the rate of florpyrauxifen-benzyl can be increased to adequately control barnyardgrass because rice injury will likewise increase.

The inherited mechanism for reduced sensitivity to florpyrauxifen-benzyl in barnyardgrass is unknown but likely persisted in populations prior to commercialization and launch of the herbicide. Conversely, barnyardgrass accession screenings conducted by Miller et al. (2018) did not observe a reduced sensitivity to florpyrauxifen-benzyl when applied to 152 barnyardgrass accessions. The widespread use of florpyrauxifen-benzyl on rice acres in 2018 aided in the identification of troublesome barnyardgrass accessions.

Practical Applications

From the data collected, it is clear that some barnyardgrass accessions possess a biochemical mechanism that aids in the detoxification of florpyrauxifen-benzyl. Therefore, where accessions with reduced sensitivity reside, florpyrauxifen-benzyl is not a viable option for barnyardgrass control. As a result, alternative means of control need to be utilized to adequately remove barnyardgrass from mid-South rice fields.

Acknowledgments

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

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Table 1. The mean efficacy of florpyrauxifen-benzyl + methylated seed oil at 0.24 L/ac on 6 barnyardgrass accessions and cultivated rice at 14 days after treatment (the 1x rate of florpyrauxifen-benzyl was 12.14 g ae/ac).

	Dose Response								
Accession	**1/16x**	**1/8x**	**1/4x**	**1/2x**	**1x**	**2x**	**4x**	**8x**	**16x**
	(% of nontreated)								
Susceptible	61 a†	89 a	94 a	98 a	99 a	100 a			
92	36 b	68 b	78 b	81 b	91 a	95 a			
18		7 d	27 c	43 cd	56 c	73 b	73 ab		
169		23 c	28 c	55 c	73 b	79 b	84 a		
157		11 cd	32 c	36 d	39 d	54 c	63 bc		
73			6 d	13 e	36 d	40 c	57 c	73 a	
Rice				8 e	6 e	19 d	25 d	48 b	55

† Means with non-alike letters within a column are significantly different based on Fisher's protected least significant difference with α = 0.05. Means in different columns should not be compared.

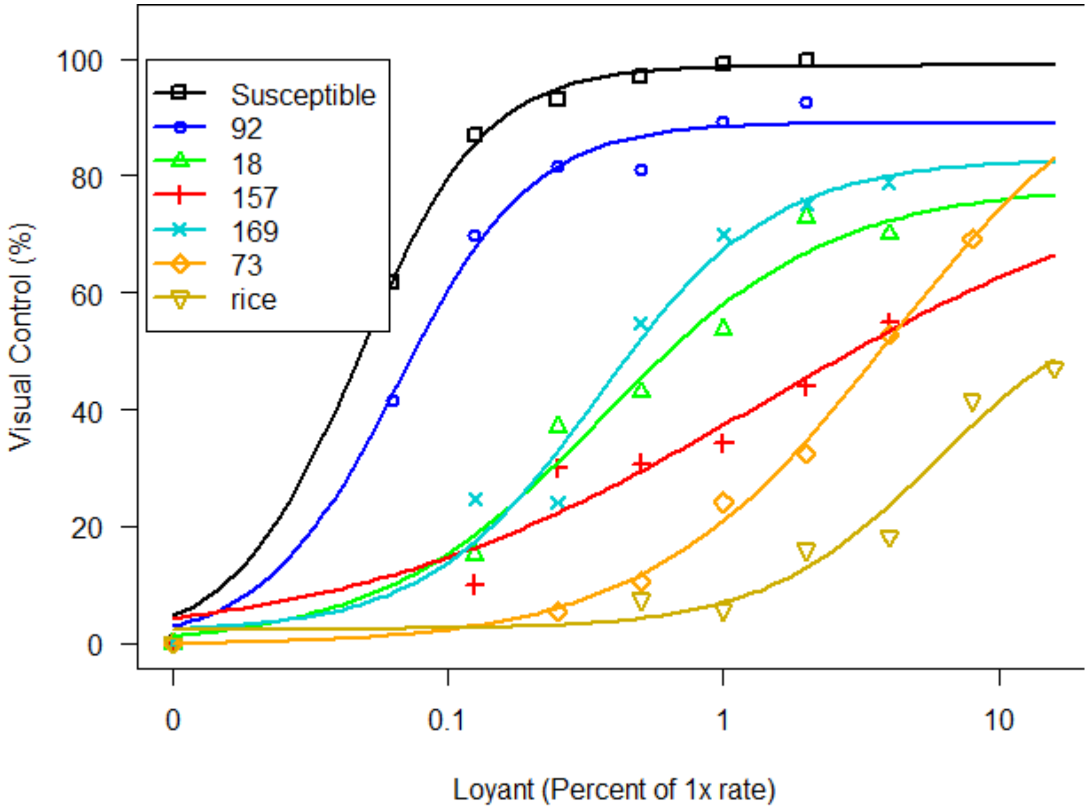

Fig. 1. Least mean square regression curve for florpyrauxifen-benzyl control on 5 barnyardgrass accessions and the three rice cultivars.

The Influence of Soil Moisture on Weed Control with Loyant

M.L. Zaccaro,[1] J.K. Norsworthy,[1] T. Butts,[2] and J.W. Beesinger[1]

Abstract

Loyant herbicide technology is based on a new active ingredient—florpyrauxifen-benzyl, and offers broad-spectrum weed control. Previous research reported that Loyant provided effective control of troublesome weeds in rice production, such as barnyardgrass and hemp sesbania. Researchers also reported that the herbicide provided control of Palmer amaranth, a problematic weed, especially in furrow-irrigated rice systems. A field experiment was established in 2019 to evaluate the effect of soil moisture and herbicide applications that included florpyrauxifen-benzyl on weed control and crop safety. Results showed that the treatments tested did not cause visible injury during the season. All treatments, including Loyant, were very efficacious on barnyardgrass; and even at 48 days after treatment, control was greater than 94%. Loyant treatments also effectively controlled hemp sesbania. Average rough grain yield was 240 bu./ac in Loyant-treated plots, and no statistical differences were observed among the treatments. In conclusion, treatments using Loyant were not statistically influenced by soil moisture at application and provided effective weed control. According to these results, it is possible to include Loyant herbicide as a weed control option in non-flooded and flooded rice production systems.

Introduction

Corteva Agroscience™ launched the Loyant™ technology recently in the 2018 growing season. This technology is based on a novel active ingredient—florpyrauxifen-benzyl, and offers broad-spectrum weed control. Previous research reported that Loyant was highly effective in controlling troublesome weeds in rice production, such as barnyardgrass (*Echinochloa crus-galli*) and hemp sesbania (*Sesbania herbacea*) (Miller and Norsworthy, 2018). Furthermore, the same research reported that florpyrauxifen-benzyl also provided control of Palmer amaranth (*Amaranthus palmeri*), a problematic weed in lower soil moisture conditions than the traditional flooded rice.

Barnyardgrass, one of the most challenging weeds to be controlled in rice production, has evolved resistance to seven modes of action, including synthetic auxins, such as quinclorac (Heap, 2020). However, reports have shown that Loyant, which is classified as a synthetic auxin, controlled quinclorac-resistant barnyardagrass because its activity is based on a different site of action than quinclorac (Lee et al., 2014).

Therefore, due to the flexibility of the Loyant herbicide, and its good efficacy to control weeds, we hypothesized that higher soil moisture would promote better weed control in rice. The objective of this field study was to evaluate the effect of soil moisture and herbicide applications that included florpyrauxifen-benzyl on weed control and crop safety.

Procedures

A field experiment was conducted in 2019 at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC) near Stuttgart, Arkansas. A long-grain hybrid rice variety (RT XP753) was planted on 25 April at the rate of 11 seeds/row-ft, and then plots were established measuring 7 × 17 ft. Herbicide treatments were made on 30 May, when barnyardgrass was at the 4-leaf growth stage. The field trial was set up as a split-plot design with 4 replications, where the main-plot factor was the soil moisture at application (wet or dry), and the subplot factor was the herbicide treatments. Herbicide treatments were Loyant at 1 pt/ac, Loyant plus methylated seed oil (MSO) at 0.5 pt/ac, and a premixture of cyhalofop + florpyrauxifen-benzyl (16.9% + 1.26%) at 28 fl oz/ac plus MSO. A nontreated check was included in this experiment. The plots with different soil moisture treatments were kept in separate bays. Wet treatments were flushed before herbicide application to increase soil moisture. The herbicide treatments were applied using a CO_2-pressurized backpack sprayer coupled with AIXR 110015 nozzles, calibrated to deliver 15 gal/ac. All plots were maintained according to the University of Arkansas System Division of Agriculture's Cooperative Extension Service recommendations.

Data collection included crop injury and weed control at 14, 28, and 48 days after treatment (DAT). Rice grain yield was harvested at maturity utilizing a small-plot combine. Data were subjected to analysis of variance, and appropriate means were separated using the LSMEANS procedure JMP Pro v. 14 (SAS Institute, Inc., Cary, N.C.) with a significance level of 0.05.

Results and Discussion

No differences in the parameters measured were observed between the two moisture regimes ($P = 0.05$). The treatments tested did not result in visible injury during the season (Table 1).

All treatments controlled barnyardgrass 100% at 14 DAT. By 28 DAT, the premix treatment with cyhalofop + florpyrauxifen-benzyl and MSO controlled barnyardgrass 100% and was statisticcally greater than Loyant alone (97%). By 48 DAT, the treatments were not statistically different, and the control ranged from 94% to 97% (data not shown). The treatments tested provided excel-

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

[2] Assistant Professor, Department of Crop, Soil, and Environmental Sciences, Lonoke.

lent control (100%) of hemp sesbania (data not shown). Average rough grain yield was 240 bu./ac, and no statistical differences were observed among the treatments (Table 1). Therefore, we rejected our hypothesis because treatments using Loyant were not statistically influenced by soil moisture at application and provided outstanding weed control.

Even though our results showed that Loyant was a safe herbicide option on rice, the herbicide label warns about the potential risk of injury to medium-grain and long-grain hybrid rice; therefore, the choice of a tolerant variety is important before utilizing the herbicide (Anonymous, 2017).

Practical Applications

According to the results of this experiment, it is possible to include Loyant herbicide as a weed control option in both non-flooded and flooded rice production systems. Weed control ratings in both soil moisture conditions were high for the weed species tested. We did not observe injury from any treatments applied to the crop. Furthermore, the addition of this new technology and site of action would increase the opportunity for controlling multiple resistant weeds while reducing selection for resistance to the herbicides that are currently being used in rice production systems.

Acknowledgments

We would like to express our gratitude for funding and support from the Arkansas Rice Research and Promotion Board and the support provided by the University of Arkansas System Division of Agriculture.

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Table 1. Rice injury and barnyardgrass control at 14 and 28 days after treatment (DAT), and grain yield influenced by herbicide treatment, across soil moisture regimes.

Treatment	Herbicide Rate	Visible injury 14 DAT	Visible injury 28 DAT	Barnyardgrass control 14 DAT	Barnyardgrass control 28 DAT	Rough rice yield
	(per acre)	---------------- % of nontreated			----------------	bu./acre
Loyant	1 pt	0[†]	0	100	97 b	244
Loyant + MSO[‡]	1 pt + 0.5 pt	0	0	100	98 ab	238
[Cyhalofop+florpyrauxifen-benzyl] + MSO	28 fl oz + 0.5 pt	0	0	100	100 a	237
Nontreated	-	-	-	-	-	234

[†] Means followed by the same letter within a column are not statistically different at a α = 0.05.

[‡] Abbreviations: MSO, methylated seed oil.

Late-Season Nitrogen Application on Hybrid Rice and the Effects on Grain and Milling Yield

D.T. Bolton,[1] T.L. Roberts,[1] J.T. Hardke,[2] K.A. Hoegenauer,[1] B.D. Hurst,[1] D.E. Kirkpatrick,[1] and R.B. Morgan[1]

Abstract

Hybrid rice (*Oryza sativa* L.) has accounted for nearly 50% of Arkansas' total rice acres harvested during the last decade. Previous research conducted on the current recommendation of applying 30 lb nitrogen (N)/ac to hybrid rice cultivars at the late-boot growth stage indicated an increase in both grain and milling yields. The conclusions from previous research suggested that significant increases in grain and milling yields were due to the addition of a late-season N application; however, more research is needed to determine if the late-season N application is necessary due to inconsistent results. A study was initiated to examine grain and milling yields on hybrid rice when implementing a late-season N application across varying preflood N application rates. The RiceTec (RT) hybrids, RT Gemini 214 CL and RT XP753, were used in this study and are the most common hybrid rice cultivars grown in Arkansas. These two cultivars were planted at the University of Arkansas System Division of Agriculture's Pine Tree Research Station (PTRS) near Colt, Arkansas, on a silt loam soil, and the Rohwer Research Station (RRS) near Rohwer, Arkansas on a clay soil. Results indicate that there is a positive impact from the late-season N application on both grain and milling yields from both cultivars at each of the locations. When late-season N was applied, there was an increase of 11 to 16 bu./ac across the two locations. Also, the late-season N application resulted in a significant increase in head rice milling yield from 1% to 5% across both locations but showed no significant difference in total rice. When observing head rice yields from various plant components (main stem vs. tillers) within the same plots, there is a significant increase in head rice yield when applying the late-season N that is equal across both main steams and tillers. It is apparent that the late-season N application results in significant increases in both grain and milling yields. Further research is needed to better understand the relationship contributing to increased grain yield and milling yields when late-season N is applied to hybrid rice and define the physiological mechanism for this response and help predict when and where it will occur.

Introduction

Hybrid rice cultivars account for approximately 50% of Arkansas rice-producing acres. The two most common hybrid rice cultivars in 2018 were RT XP753 and RT Gemini 214 CL, accounting for over 30% of total rice planted (Hardke, 2018). The preflood N rates for hybrid cultivars are managed the same as pure-line cultivars and are determined via cultivar by N trials. The preflood N application is traditionally made at the V5 growth stage to first tiller rice prior to the establishment of the permanent flood in a direct-seeded, delayed-flood rice production system (Roberts et al., 2018).

The only difference in N management between pure-line and hybrid cultivars is that 30 lb N/ac is added at the late-boot growth stage into the flood several weeks later than a midseason N application would be made to pure-line cultivars. The late-season N can only influence the third yield component of rice, the average weight per seed (Moldenhauer et al., 2018), and it has been shown that an increase in N above 30 lb N/ac at this time does not lead to a resultant increase in yield (Norman et al., 2007). This is what distinguishes the N management scheme of hybrid rice from the pure-line cultivars, as pure-line cultivars receive 45 lb N/ac at midseason or 2-inch internode elongation (Roberts et al., 2018). The late-boot N application to hybrids typically results in reduced lodging and has the potential to enhance grain (Norman et al., 2006, 2007, 2008) and milling (Walker et al., 2008) yields. Results from Smartt et al. (2018), suggested that there were positive results from a late-boot application to hybrid rice at times but further work needs to be conducted to better understand the physiological effects of the late-season N application and its impact on hybrid rice grain and milling yield. The objective of this study is to evaluate grain and milling yields when applying late-season N to hybrid rice across varying soil textures, preflood N rates, and hybrid cultivars.

Procedures

Two studies were conducted in 2019 at the University of Arkansas System Division of Agriculture's Pine Tree Research Station (PTRS) near Colt, Arkansas, on a silt loam soil, and the Rohwer Research Station (RRS) near Rohwer, Arkansas, on a clay soil. The two cultivars planted were RT Gemini 214 CL and RT XP753 and were planted at 25 lb seed/ac on both the silt loam and clay soil. Plots were established that measured 6 × 16 ft, with a 7.5-inch drill spacing. There were six preflood N treatments implemented; however, an additional 30 lb N/ac was

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[1] Graduate Assistant, Professor, Lab Technician, Graduate Assistant, Graduate Assistant, and Graduate Assistant, respectively, Department of Crop, Soil, and Environmental Sciences, Fayetteville.

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

added to each preflood N rate for the clay soil to accommodate for the increased N rate recommended on heavy textured soils (Roberts et al., 2018). The preflood N rates for the study were 0, 30, 60, 90, 120, and 150 lb N/ac for the silt loam soil and 0, 60, 90, 120, 150, and 180 lb N/ac for the clay soil. Preflood N was applied in the form of urea (46% N), at the 4- to 5-leaf growth stage (Counce et al., 2000). and followed by the establishment of the permanent flood at both locations within 48 hours. The late-season N application (either 0 or 30 lb N/ac) was applied by hand directly into the floodwater when the rice reached the late-boot growth stage. Each unique cultivar × preflood N rate × late-season N rate treatment combination was replicated four times at each location. The untreated control plots that were included in the study did not receive a preflood or late-season N application. Prior to harvest, grain samples were taken from each plot by separating the grain held on the main stems from grain that was held on the outside tillers. These samples remained separate and were milled individually to determine if potential differences in milling quality existed amongst the main stems and tillers. The center 4 rows of each plot were then harvested with a combine, and the grain was collected for both whole plot grain yield and milling yield. Whole plot grain yields were adjusted to 12% moisture content for comparison. Milling yield was determined on a PAZ-1 laboratory benchtop mill (Zaccaria USA, Anna, Texas) with a known check sample included every 24 samples to ensure the mill was set properly throughout the duration of milling. The experimental design at both locations for whole plot grain and milling yield was a 2 (cultivar) × 6 (preflood N rate) × 2 (late-season N application) factorial arranged in a completely randomized block design. The experimental design at both locations for determining differences in milling yield amongst plant parts was a 2 (cultivar) × 6 (preflood N rate) × 2 (late-season N application) × 2 (plant component) factorial arranged in a completely randomized block design. The statistical software package JMP 15.0 was used to determine the analysis of variance for grain yield, whole plot milling, and plant component milling yield. The means were separated using a studentized *T*-test at $\alpha = 0.05$.

Results and Discussion

There were no two- or three-way main effect interactions from either location when analyzing grain yield results. The main effect of preflood N rate was significant, and an increase in grain yield was seen as preflood N rate increased. At the PTRS location, from the lowest preflood N rate to the highest, the grain yield increased from 134 bu./ac to 236 bu./ac with all treatments being significantly different from the other (Table 1). The main effect of cultivar on rice grain yield was also significant with RT Gemini 214 CL out yielding RT XP753 194 bu./ac to 185 bu./ac. The main effect of late-season N application led to a significant grain yield increase when it was applied at the PTRS location, where the increase in grain yield from the addition of 30 lb N/ac was 11 bu./ac. The RRS also did not have any two- or three-way interactions and only resulted in statistically significant differences amongst the preflood N rates and the late-season N application. There was a significant increase in grain yield from 162 bu./ac to 207 bu./ac from the lowest to the highest preflood N rate. When the late-season N application was applied at the RRS, there was an increase in grain yield of 16 bu./ac.

Whole plot head rice at the PTRS location was influenced by the two-way interaction of cultivar and preflood N rate as well as the main effect of late-season N application (Table 2). The cultivar RT Gemini 214 CL at PTRS, milled higher across lower preflood N rates than RT XP753 resulting in the significant interaction. There was a significant increase in head rice milling percentages when the late-season N was applied with an increase from 54% to 56% head rice. Whole plot milling yield at the RRS was influenced by the three main effects of preflood N rate, cultivar, and late-season N application, and no significant interactions were identified. The cultivar RT Gemini 214 CL had a significantly higher head rice percentage (42%) compared to RT XP753 (32%) (Table 3). Preflood N rates also resulted in a significant difference and resulted in none of the preflood N rates being statistically similar, with the increase being from 25% to 48% head rice, from the lowest to highest preflood N rate. Late-season N application significantly increased head rice percentages from 35% to 39%.

Milling yields of various plant parts (not whole plot milling) were compared to determine if these differences were worthy of further investigation in future research projects. At the PTRS location, head rice milling of plant part (main stems vs. tillers) differences were significantly influenced by the main effects of cultivar, late-season N application, and preflood N rates. There were no statistical differences in the head rice within the plant part factor of main stems and tillers. The significant difference of cultivar indicated that RT Gemini 214 CL had significantly higher head rice milling yield of 61% compared to RT XP753 with a head rice milling yield of 59% (Table 4). As the preflood N rate increased, the head rice of both plant parts increased with all treatments being significantly different, with a range of 57% to 63% head rice from the lowest to highest preflood N rate. A late-season N application of 30 lb N/ac significantly increased head rice milling by 2%. At the RRS location, all main effects were deemed to have a significant impact on plant part milling yield with no interactions. The cultivar RT Gemini 214 CL had a statistically higher head rice milling yield than RT XP753 by 19%. There was also a statistical increase from 33% to 39% head rice when applying the late-season N application when averaged across both cultivars. As preflood N rate increased, head rice milling also increased for main stems and tillers with all rates being significantly different except for the two highest preflood N rates being statistically similar. There was an increase of 23% to 49% head rice from the lowest to highest preflood N rates at the RRS location. A statistical difference between plant parts was observed at this location, with the main stem being 4% higher in head rice milling than tillers. There were no significant differences between any total rice milling factors for whole plot or plant part studies.

Practical Applications

The results of this study show that the late-season N application has many positive effects on both grain and milling yields in hybrid rice. The late-season N application appears to have more of an impact on yields across all three factors at the RRS. The RRS location was situated on a Sharkey clay soil, unlike PTRS, and had different weather conditions throughout the season, especially near harvest. The results from the RRS indicated lower overall grain and milling yield compared to PTRS but showed that the late-season N application had more of a positive effect on these yields. Plant part milling shows that the tillers are producing lower yields of head rice when compared to main stem head rice. This could indicate that even in perfect growing conditions, the late-season N application still increases yields and is beneficial; but in years with less than desirable environmental conditions, the application is a necessity for growers producing hybrid rice to achieve high grain and milling yields. This is only preliminary data and needs to be replicated across more site-years to verify the results of this work. This experiment will continue in the summer of 2020.

Acknowledgments

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

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Table 1. Influence of preflood nitrogen (N) rate, late-season N application, and cultivar on rice grain yield at two locations during 2019.

Treatment Preflood N rate[§]	PTRS[†]	RRS[‡]
Rate 1	96 f[¶]	91 d
Rate 2	134 e	162 c
Rate 3	167 d	169 c
Rate 4	195 c	188 b
Rate 5	215 b	198 a
Rate 6	236 a	207 a
Late-season N rate		
0 lb N/ac	184 b	177 b
30 lb N/ac	195 a	193 a
Cultivar		
RT Gemini 214 CL	194 a	182 a
RT XP753	185 b	187 a

[†] PTRS = University of Arkansas System Division of Agriculture's Pine Tree Research Station, Colt, Ark.

[‡] RRS = University of Arkansas System Division of Agriculture's Rohwer Research Station, Rohwer, Ark.

[§] Preflood N rates 1, 2, 3, 4, 5, and 6 correspond to 0, 30, 60, 90, 120, 150 lb N/ac for PTRS and 0, 60, 90, 120, 150, 180 lb N/ac for RRS.

[¶] Values with different letters show significant differences. Significant values do not carry-over dotted horizontal lines due to no main effect interactions. Locations are not a factor.

Table 2. Influence of preflood nitrogen (N) rate, late-season N application, and cultivar on rice whole plot milling yield at the University of Arkansas System Division of Agriculture's Pine Tree Research Station (PTRS), Colt, Arkansas, during 2019.

Treatment Preflood N rate[†]	% Head Rice	Cultivar
Rate 1	51 e[‡]	RT Gemini 214 CL
Rate 2	51 de	
Rate 3	54 c	
Rate 4	54 bc	
Rate 5	56 b	
Rate 6	59 a	
Rate 1	48 f	RT XP753
Rate 2	50 ef	
Rate 3	51 e	
Rate 4	53 b	
Rate 5	58 a	
Rate 6	60 a	
Late-Season N application		
0 lb N/ac	54 b	
30 lb N/ac	56 a	

[†] Preflood N rates 1, 2, 3, 4, 5, and 6 correspond to 0, 30, 60, 90, 120, 150 lb N/ac for PTRS.

[‡] Values with different letters show significant differences. Significant values do not carryover dotted horizontal lines due to no main effect interactions. Locations are not a factor.

Table 3. Influence of preflood nitrogen (N) rate, late-season N application, and cultivar on rice whole plot milling yield at the University of Arkansas System Division of Agriculture's Rohwer Research Station (RRS), Rohwer, Arkansas, during 2019.

Treatment Preflood N rate†	% Head Rice
Rate 1	23 e
Rate 2	25 e
Rate 3	31 d
Rate 4	37 c
Rate 5	44 b
Rate 6	48 a
Late-Season N application	
0 lb N/ac	35 a
30 lb N/ac	39 b
Cultivar	
RT Gemini 214 CL	42 a
RT XP753	32 b

† Preflood N rates 1, 2, 3, 4, 5, and 6 correspond to 0, 60, 90, 120, 150, 180 lb N/ac for RRS.

‡ Values in parenthesis with different letters show significant differences. Significant values do not carryover dotted horizontal lines due to no main effect interactions. Locations are not a factor.

Table 4. Influence of preflood nitrogen (N) rate, late-season N application, cultivar, and plant part (main stem vs. tiller) on plant part head rice milling yield at two locations during 2019.

Treatment Preflood Rate§	PTRS†	RRS‡
Rate 1		
Rate 2	57 e¶	23 e
Rate 3	58 d	29 d
Rate 4	60 c	37 c
Rate 5	62 b	44 b
Rate 6	63 a	49 a
Late-season N application		
0 lb N/ac	59 b	33 b
30 lb N/ac	61 a	39 a
Cultivar		
RT Gemini 214 CL	61 a	46 a
RT XP753	59 b	27 b
Plant Part		
Main stem	60 NS	38 a
Tiller	60 NS	34 b

† PTRS = University of Arkansas System Division of Agriculture's Pine Tree Research Station, Colt, Ark.

‡ RRS = University of Arkansas System Division of Agriculture's Rohwer Research and Station, Rohwer, Ark.

§ Preflood N rates 1, 2, 3, 4, 5, and 6 correspond to 0, 30, 60, 90, 120, 150 lb N/ac for PTRS and 0, 60, 90, 120, 150, 180 lb N/ac for RRS.

¶ Values in parenthesis with different letters show significant differences. Significant values do not carryover dotted horizontal lines due to no main effect interactions. Locations are not a factor. Values with (NS) are not significantly different.

Grain Yield Response of Eleven New Rice Cultivars to Nitrogen Fertilization

*E. Castaneda-Gonzalez,[1] T.L. Roberts,[2] J.T. Hardke,[1] N.A. Slaton,[3] K.A.K. Moldenhauer,[1]
X. Sha,[1] D.L. Frizzell,[1] M.W. Duren,[4] and T.D. Frizzell[1]*

Abstract

The objective of the cultivar × nitrogen (N) studies is to determine the optimal N fertilizer rates for new rice (*Oryza sativa* L.) cultivars across the array of soils and environments encountered in the Arkansas rice-growing region. The eleven cultivars studied in 2019 were: ARoma 17, CLJ01, CLL15, CLL16, CLM04, Jewel, Lynx, PVL01, PVL02, the experimental line ARX7-1084, and Diamond. Seed treatment and seeding rates were determined following current recommendations and production practices. The grain yields were good to excellent for all the cultivars studied at the three locations in 2019: University of Arkansas System Division of Agriculture's Northeast Research and Extension Center (NEREC), Keiser, Arkansas, on a Sharkey Clay (Vertic Haplaquepts) soil; the Pine Tree Research Station (PTRS) near Colt, Arkansas, on a Calloway silt loam (Glossaquic Fragiudalfs) soil series; and the Rice Research and Extension Center (RREC), near Stuttgart, Arkansas, on a Dewitt silt loam (Typic Albaqualfs) soil. This is the first year the cultivars ARoma 17, CLJ01, CLL15, CLL16, CLM04, Jewel, Lynx, and PVL02 are included in the cultivar × N rate study; therefore there is insufficient data to make a recommendation at this time. Multiple years of results for PVL01 indicate this cultivar 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 intent of the cultivar × N fertilizer rate trials is to record and analyze the grain yield performance of new rice cultivars over a range of fertilizer rates on a representative clay and two silt loam soils as well as diverse growing environments existing in Arkansas. The goal is to determine the appropriate N fertilizer rates conducive to maximize grain yields and provide 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. Eleven new cultivars were included and studied in 2019 at three locations. The cultivars entered were ARoma 17, CLJ01, CLL15, CLL16, CLM04, Jewel, Lynx, PVL01, and PVL02, the experimental line ARX7-1084, and Diamond. There was no lodging reported at any of the trial locations for 10 of the 11 cultivars at even the highest preflood N rates.

Procedures

The cultivar × N fertilizer rate studies were established in the following locations: University of Arkansas System Division of Agriculture's Northeast Research and Extension Center (NEREC), Keiser, Arkansas, on a Sharkey Clay (Vertic Haplaquepts) soil; the Pine Tree Research Station (PTRS) near Colt, Arkansas, on a Calloway silt loam (Glossaquic Fragiudalfs) soil series; and the Rice Research and Extension Center (RREC), near Stuttgart, Arkansas, on a Dewitt silt loam (Typic Albaqualfs) soil. The experimental design utilized for data analysis for all locations and each cultivar was a randomized complete block with four replications. All seed of each cultivar was treated with fungicide and insecticide according to current recommendations and practices in addition to a zinc seed treatment. All experimental plots were direct-seeded in 8 rows at 7.5-in. spacing and 17 ft in length at a rate of 35 seed/ft^2. A single preflood N fertilizer application was employed in all cultivars across all locations and was applied 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) was treated with the 0 to 210 lb of N/ac rate structure with the omission of the 60 lb N/ac rate. Pertinent agronomic dates and practices for each location are reported in Table 1. The permanent flood was established either the same day or within a few days of the preflood N application and maintained until maturity of the rice crop. At maturity, the flood was released and within two weeks, the four center rows of each plot were harvested and grain moisture content and yield were recorded. Yields were calculated as bushels (bu.) per acre (ac) and adjusted to 12% moisture, with a bushel of rice weighing 45 pounds (lb). Statistical analysis was conducted using PROC GLM,

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[1] Program Associate, Rice Extension Agronomist, Professor, Professor, Program Associate, and Program Technician, respectively, Department of Crop, Soil, and Environmental Sciences, Stuttgart.

[2] Associate Professor, Department of Crop, Soil, and Environmental Sciences, Fayetteville.

[3] Assistant Director, Agricultural Experiment Station, Fayetteville.

[4] Center Director, Northeast Research and Extension Center, Keiser.

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

In 2008, a single preflood N application was adopted in all cultivar × N studies in response to the rising cost of N fertilizer and the preference of medium to short stature, semidwarf, stiff straw plant type currently grown. These cultivars typically reach maximal yields when less N is applied in a single preflood application in comparison with the traditional two-way split application. Usually cultivars receiving a single preflood application required 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-inch internode elongation growth stages. Hence if 150 lb N/ac is recommended for a two-way application, then 120 to 130 lb N/ac is recommended for a single preflood application considering that 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 two 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 three weeks after flood establishment (Roberts et al., 2018).

Overall, the yields for the 2019 cultivar × N rate trials were good to excellent for the majority of the 11 cultivars included. Maximal yields ranged from 160–215 bu./ac for the NEREC location, 152–219 bu./ac at the PTRS location, and 178–232 bu./ac for the RREC location. There were no lodging scores reported for 10 of the 11 entries across even the highest preflood N rates. The only variety that exhibited lodging was PVL02 at the two highest preflood N rates at the NEREC and RREC locations and was at most reported to be 5%. Yield results and response to N of Diamond (check cultivar) in this year's cultivar × N trial support data from previous years and indicate that the overall results of the trial fall in line with previous research.

The cultivar ARoma 17 achieved a maximum yield of 193 bu./ac at the NEREC location followed by 192 bu./ac at RREC and 158 bu./ac at PTRS when the highest N rates were applied of 210 lb N/ac and 180 N lb/ac for the clay and silt loam locations, 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 180 lb N/acre for the clay soil and 120 lb N/ac for the two silt loam soils. These results will be combined with additional data from subsequent years to identify the optimal N rate for this cultivar.

The rice cultivar CLJ01 exhibited similar yields to ARoma 17 across all three locations. The highest yields were observed at the high N rates for both the NEREC location as well as the RREC location with 197 bu./ac at the RREC and 180 bu./ac at NEREC (Table 3). The yields at the PTRS location were anywhere from 20–40 bu./ac lower than those reported for NEREC and RREC, and the highest yield was achieved with 150 lb N/ac. The lowest yield maximizing N rate was 150, 150, and 180 lb N/ac for the NEREC, PTRS, and RREC locations, respectively. No lodging was reported for CLJ01 across any of the locations or preflood N rates tested, suggesting that even with high N rates and high yield potential, the straw strength of this cultivar is adequate. Yield response for CLJ01 followed a quadratic response at the NEREC and PTRS locations; whereas the yield response at RREC was linear, meaning that there was a significant increase in yield with each increase in preflood N rate. The least significant differences reported for the three locations were all below 12 bu./ac and indicate that the yields were fairly consistent within a preflood N rate and that yield response for N rates at or above 150 lb N/ac were similar.

The cultivar CLL15 was one of the most consistent yielding cultivars across all locations with maximal yields near or above 200 bu./ac (Table 4). The lowest yield maximizing N rate was 180, 150, and 120 lb N/ac for the NEREC, PTRS, and RREC locations, respectively. This cultivar exhibits a stable trend of grain yield production with no lodging reported at any of the three locations, even at the highest preflood N rates. Additional research is needed to refine the preflood N rates for this cultivar, but it appears that when well managed, it has a very high yield potential and standability. Although the yields suggested that increased preflood N rates resulted in increasing yields across all three locations, near maximal yield was often achieved with 60 lb N/ac less than the overall yield maximizing preflood N rate at each location.

The cultivar CLL16 was only included at the PTRS and RREC locations in 2019 (Table 5). The yield maximizing preflood N rate at both locations was 150 lb N/ac rate with yields of 182 bu./ac and 215 bu./ac at the PTRS and RREC locations, respectively. However, there were no significant differences in grain yield between the 120, 150 or 180 lb N/ac preflood N rates at either location. There were no reports of lodging at either of the two locations for CLL16 across any of the preflood N rates, but the fact that the lowest yield maximizing preflood N rate was 120 lb N/ac suggests that lower preflood N rates may need to be considered for this cultivar. Further research is needed to better categorize the preflood N needs for CLL16 as this is the first year it has been included in the cultivar × N trial and was only tested at two of the three locations during 2019.

Grain yields near or above 200 bu./ac were observed for the cultivar CLM04 across all three locations in 2019 (Table 6), making it one of the higher yielding cultivars. Maximal yields of 207 and 213 bu./ac were recorded at PTRS and NEREC when 150 and 210 lb N/ac were applied, respectively. A maximum yield of 198 bu./ac was achieved when 150 lb N/ac was applied at the RREC location. The lowest yield maximizing N rate was 180, 120, and 120 lb N/ac for the NEREC, PTRS, and RREC locations, respectively. Similar to the majority of the other cultivars, no lodging was reported for CLM04 at or above the yield maximizing N rate across any of the locations. Yields were stable for this cultivar across the top two (NEREC) or top three (PTRS and RREC) preflood N rates. This is the first year that CLM04 has been included in the cultivar × N trials, and further data is needed to better categorize the preflood N rates for this cultivar. 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 with 120 lb N/ac applied in a single preflood N application.

The cultivar Jewel recorded the highest grain yield among all tested cultivars and locations with 232 bu./ac at the 180 lb N/ac rate at the RREC location (Table 7). Grain yields of 182 and 185 bu./ac were achieved at the PTRS and NEREC locations with the preflood N application rates of 180 and 210 lb N/ac, respectively. Although yields were generally maximized with the highest or second highest preflood N rates at all locations, there was no statistical yield difference amongst the three highest preflood N rates at all three locations. The lowest yield maximizing N rate was 150, 120, and 120 lb N/ac for the NEREC, PTRS, and RREC locations, respectively. There was no lodging reported for Jewel across any of the locations or preflood N rates tested and with stable yields at or above 120 lb N/ac for PTRS and RREC and 150 lb N/ac at the NEREC location, it appears that these rates are sufficient to produce maximal yield across a wide range of environments.

Lynx was the only rice cultivar included in the 2019 cultivar × N trial that produced maximal yields at or above 200 bu./ac at all three locations (Table 8). This was the first year that Lynx was included in the trial, but initial results suggest excellent yield potential that appears stable across a wide range of environments and soils. The maximal yield of Lynx was achieved with the highest overall preflood N rates at NEREC and PTRS, but yield was maximized at the RREC location with the second highest preflood N rate of 150 lb N/ac. A linear yield response was seen at the PTRS location as significant yield increases were seen with each increasing preflood N rate. However, at the NEREC and RREC locations, yield plateaued with varying preflood N rates. The lowest yield maximizing N rate was 180, 180, and 120 lb N/ac for the NEREC, PTRS, and RREC locations, respectively. There was no lodging reported for Lynx across any of the preflood N rates or locations included within this study. Due to the variability in response to preflood N rates across locations, it is pertinent that further work is conducted on this cultivar to better categorize the correct preflood and season total N rate.

The 2019 growing season represents the third year that the rice cultivar PVL01 was included in the cultivar × N trials. Maximal yield for PVL01 was moderate at the NEREC and PTRS locations but very good at RREC (Table 9). Overall maximal yields for PVL01 were 161, 152, and 190 bu./ac for the NEREC, PTRS, and RREC locations, respectively. The highest preflood N rates were required to produce the maximal grain yield of PVL01 at both the PTRS and RREC locations. The second highest preflood N rate of 180 lb N/ac was required at NEREC. The lowest yield maximizing N rate for PVL01 was 150, 120, and 120 lb N/ac for the NEREC, PTRS, and RREC locations, respectively. Similar to other cultivars, there was no lodging reported across any of the locations or preflood N rates included in this trial and was consistent across the last two seasons for this cultivar. Based on this third and final year of data and the results of the previous two years that it was included in the cultivar × N trial (Norman et al., 2018; Norman et al., 2019), the rice cultivar PVL01 requires 120 lb N/ac to maximize yield on a silt loam soil when a single preflood N rate is used. If using a two-way split application, then the preflood N rate should be 105 lb N/ac with 45 lb N/ac applied at least three weeks postflood and when the rice has reached 0.5-inch internode elongation.

This was the first year PVL02 was included in the cultivar × N trials. Overall, yields were moderate to good at the three locations, with the overall highest yield reported at the RREC location. Maximal yields for PVL02 were 176, 163, and 178 bu./ac at the NEREC, PTRS, and RREC locations, respectively (Table 10). The preflood N rate required to produce maximal yield at each location varied greatly and ranged from 210 lb N/ac at NEREC to 120 lb N/ac at RREC. Cultivar PVL02 was the only one with lodging reported during the 2019 growing season. At the highest preflood N rates of 210 lb N/ac at NEREC and 180 lb/ac at RREC, there was a lodging score of 5%. Conversely, there was no lodging reported for PVL02 at the PTRS location across any of the preflood N rates implemented. The lowest yield maximizing N rate was 150, 150, and 90 lb N/ac for the NEREC, PTRS, and RREC locations, respectively.

The cultivar ARX7-1084 is an experimental release that was included in the cultivar × N rate trial for the first time in 2019. This cultivar exhibited excellent yield potential with maximal yields across the three locations ranging from 174 to 235 bu./ac (Table 11). The preflood N rate required to produce maximal yield at each location varied greatly and ranged from 180 lb N/ac at NEREC to 150 lb N/ac at RREC. There was no lodging reported for ARX7-1084 across any of the locations or preflood N rates included in this trial, indicating that this cultivar with high yield potential exhibits good standability even at the maximal preflood N rates implemented. The lowest yield maximizing N rate was 150, 150, and 120 lb N/ac for the NEREC, PTRS, and RREC locations, respectively. Although this is the first year that this cultivar has been included, it appears that this cultivar will follow closely with previous University of Arkansas System Division of Agriculture cultivar releases and require similar preflood N rates to maximize yield. At least two more years of data are needed to properly categorize the season total N rate requirement for ARX7-1084.

The cultivar Diamond was included in the study as a control and reference of comparison of the grain yield and lodging response of the new rice cultivars to the different N rates applied at the three locations (Table 12). The current N rate recommendation for Diamond is 150 lb N/ac applied in a two-way split of 105 lb N/ac at preflood and 45 lb N/ac at midseason when grown on silt loam soils and 180 lb N/ac applied in a two-way split of 135 lb N/ac at preflood and 45 lb N/ac at midseason when grown on clay soils.

Practical Applications

The cultivar × 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 when grown commercially in the Arkansas rice-growing region. The new rice cultivars included in 2019 were: ARoma 17, CLJ01, CLL15, CLL16, CLM04, Jewel, Lynx, PVL01, PVL02, and the experimental line ARX7-1084. Multiple years of results for PVL01 indicate this cultivar should have good yields with minimal to no lodging if 150 lb N/ac is applied in a two-way split of 105 lb N/ac at preflood 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 preflood followed by 45 lb N/ac applied at midseason when grown in clay soils (Norman et al., 2019).

Acknowledgments

This research was supported by the rice growers of Arkansas through the Rice Check-Off funds administered by the Arkansas Rice Research and Promotion Board, the University of Arkansas System Division of Agriculture, and Horizon Ag.

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Table 1. Pertinent agronomic information for the University of Arkansas System Division of Agriculture's Northeast Research and Extension Center (NEREC), Keiser, Ark., Pine Tree Research Station (PTRS), Colt, Ark., and the Rice Research and Extension Center (RREC), Stuttgart, Ark., during 2019.

Practices	NEREC	PTRS	RREC
Pre-plant Fertilizer	---------------	Late March 0-60-90-10	20 March 0-60-60
Planting Dates	30 April	16 May	23 April
Herbicide	29 April	17 May	24 April
Spray Dates and Spray Procedures	1 qt RoundUp + 0.5 oz FirstShot	3.2 oz League + 20 oz Facet + 8 oz Command	20 oz Obey + 3.2 oz League
Emergence Dates	12 May	22 May	3 May
Herbicide Spray Dates and Spray Procedures	29 April 1.5 pt Command + 2 oz Sharpen	4 June 0.75 oz Permit Plus + 3 qt Propanil	5 June 24 oz Ricestar + 22 oz Facet L + 0.75 oz Permit Plus
Herbicide Spray Dates and Spray Procedures	3 May 4 qt Propanil + 1 oz Herbivore	11 May 0.75 Permit Plus + 3 qt Propanil	11 May 15 oz Clincher + 1 qt COC[a]
Herbicide Spray Dates and Spray Procedures	28 May 1 oz Herbivore		14 June 20 oz Clincher + 1 qt COC
Preflood N Dates	13 June	14 June	4 June
Flood Dates	15 June	14 June	5 June
Drain Dates	30 August	4 September	28 August
Harvest Dates	9 September	16 September	5 September

[a] 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), Keiser, Ark., Pine Tree Research Station (PTRS), Colt, Ark., and the Rice Research and Extension Center (RREC), Stuttgart, Ark., during 2019.

	Grain Yield		
N Fertilizer Rate	**NEREC**	**PTRS**	**RREC**
(lb N/ac)	----------	(bu./ac)	----------
0	83.4	93.9	88.4
60	----	124.6	128.4
90	131.9	135.5	161.9
120	163.1	144.9	181.5
150	171.6	153.3	179.1
180	191.7	157.9	192.3
210	192.9	----	----
LSD$_{(\alpha=0.05)}$[a]	15.9	12.4	16.5
C.V.[b]	6.6	6.1	7.1

[a] LSD = least significant difference.

[b] C.V. = coefficient of variation.

Table 3. Influence of nitrogen (N) fertilizer rate on the grain yield of CLJ01 rice at the University of Arkansas System Division of Agriculture's Northeast Research and Extension Center (NEREC), Keiser, Ark., Pine Tree Research Station (PTRS), Colt, Ark., and the Rice Research and Extension Center (RREC), Stuttgart, Ark., during 2019.

	Grain Yield		
N Fertilizer Rate	**NEREC**	**PTRS**	**RREC**
(lb N/ac)	----------	(bu./ac)	----------
0	68.3	89.0	77.7
60	----	132.7	115.9
90	129.1	147.3	149.9
120	144.9	154.1	168.5
150	162.4	165.3	182.2
180	171.6	151.5	196.6
210	179.8	----	----
LSD$_{(\alpha=0.05)}$[a]	11.1	10.7	9.0
C.V.[b]	5.2	5.1	4.0

[a] LSD = least significant difference.

[b] C.V. = coefficient of variation.

Table 4. Influence of nitrogen (N) fertilizer rate on the grain yield of CLL15 rice at the University of Arkansas System Division of Agriculture's Northeast Research and Extension Center (NEREC), Keiser, Ark., Pine Tree Research Station (PTRS), Colt, Ark., and the Rice Research and Extension Center (RREC), Stuttgart, Ark., during 2019.

	Grain Yield		
N Fertilizer Rate	**NEREC**	**PTRS**	**RREC**
(lb N/ac)	----------	(bu./ac)	----------
0	89.3	90.1	96.2
60	----	151.4	153.6
90	172.7	163.0	162.6
120	187.7	182.5	187.6
150	199.1	192.8	197.3
180	210.5	197.4	212.0
210	214.5	----	----
LSD$_{(\alpha=0.05)}$[a]	9.5	11.1	19.0
C.V.[b]	3.5	4.5	7.5

[a] LSD = least significant difference.

[b] C.V. = coefficient of variation.

Table 5. Influence of nitrogen (N) fertilizer rate on the grain yield of CLL16 rice at the University of Arkansas System Division of Agriculture's Pine Tree Research Station (PTRS), Colt, Ark., and the Rice Research and Extension Center (RREC), Stuttgart, Ark., during 2019.

	Grain Yield	
N Fertilizer Rate	**PTRS**	**RREC**
(lb N/ac)	------------------------- (bu./ac)	--------------------------
0	90.2	119.1
60	141.7	170.9
90	152.1	183.9
120	174.6	202.7
150	181.5	214.9
180	179.3	207.8
210	----	----
LSD$_{(\alpha=0.05)}$[a]	13.5	10.9
C.V.[b]	5.8	3.9

[a] LSD = least significant difference.

[b] C.V. = coefficient of variation.

Table 6. 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), Keiser, Ark., Pine Tree Research Station (PTRS), Colt, Ark., and the Rice Research and Extension Center (RREC), Stuttgart, Ark., during 2019.

		Grain Yield	
N Fertilizer Rate	**NEREC**	**PTRS**	**RREC**
(lb N/ac)	--	(bu./ac)	--
0	87.1	117.8	106.6
60	----	162.8	127.0
90	147.2	193.0	158.5
120	169.0	201.6	181.8
150	189.7	206.5	197.7
180	210.3	205.7	196.3
210	212.9	----	----
LSD$_{(\alpha=0.05)}$[a]	14.3	8.0	19.8
C.V.[b]	5.6	2.9	8.1

[a] LSD = least significant difference.

[b] C.V. = coefficient of variation.

Table 7. 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), Keiser, Ark., Pine Tree Research Station (PTRS), Colt, Ark., and the Rice Research and Extension Center (RREC), Stuttgart, Ark., during 2019.

		Grain Yield	
N Fertilizer Rate	**NEREC**	**PTRS**	**RREC**
(lb N/ac)	--	(bu./ac)	--
0	68.7	88.1	99.6
60	----	140.8	150.8
90	138.5	151.4	187.0
120	160.2	176.6	208.7
150	166.6	177.9	223.7
180	184.5	182.0	231.9
210	184.0	----	----
LSD$_{(\alpha=0.05)}$[a]	20.6	12.8	15.4
C.V.[b]	9.1	5.6	5.6

[a] LSD = least significant difference.

[b] C.V. = coefficient of variation.

Table 8. 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), Keiser, Ark., Pine Tree Research Station (PTRS), Colt, Ark., and the Rice Research and Extension Center (RREC), Stuttgart, Ark., during 2019.

	Grain Yield		
N Fertilizer Rate	**NEREC**	**PTRS**	**RREC**
(lb N/ac)	----------	**(bu./ac)**	----------
0	80.8	104.7	116.3
60	----	162.0	171.9
90	158.2	186.5	197.3
120	170.6	203.3	205.5
150	194.8	219.0	221.8
180	214.0	229.3	218.3
210	220.6	----	----
LSD$_{(\alpha=0.05)}$[a]	18.7	9.3	17.1
C.V.[b]	7.2	3.4	6.0

[a] LSD = least significant difference.

[b] C.V. = coefficient of variation.

Table 9. Influence of nitrogen (N) fertilizer rate on the grain yield of PVL01 rice at the University of Arkansas System Division of Agriculture's Northeast Research and Extension Center (NEREC), Keiser, Ark., Pine Tree Research Station (PTRS), Colt, Ark., and the Rice Research and Extension Center (RREC), Stuttgart, Ark., during 2019.

	Grain Yield		
N Fertilizer Rate	**NEREC**	**PTRS**	**RREC**
(lb N/ac)	----------	**(bu./ac)**	----------
0	71.6	75.8	99.1
60	----	122.1	152.4
90	125.3	143.8	168.2
120	142.8	149.7	188.9
150	151.8	151.6	187.2
180	161.0	151.6	189.5
210	158.3	----	----
LSD$_{(\alpha=0.05)}$[a]	14.3	11.0	12.8
C.V.[b]	7.0	5.5	5.2

[a] LSD = least significant difference.

[b] C.V. = coefficient of variation.

Table 10. Influence of nitrogen (N) fertilizer rate on the grain yield of PVL02 rice at the University of Arkansas System Division of Agriculture's Northeast Research and Extension Center (NEREC), Keiser, Ark., Pine Tree Research Station (PTRS), Colt, Ark., and the Rice Research and Extension Center (RREC), Stuttgart, Ark. during 2019.

	Grain Yield		
N Fertilizer Rate	**NEREC**	**PTRS**	**RREC**
(lb N/ac)	----------	**(bu./ac)**	----------
0	65.0	81.0	93.0
60	----	126.3	147.9
90	129.6	141.6	169.3
120	144.6	155.2	177.6
150	158.9	162.6	175.6
180	167.8	157.8	172.3 (5)[a]
210	175.8 (5)[a]	----	----
LSD$_{(\alpha=0.05)}$[b]	22.0	6.8	15.8
C.V.[c]	10.4	3.3	6.7

[a] Number in parentheses to the side of the grain yield are lodging percentages.

[b] LSD = least significant difference.

[c] C.V. = coefficient of variation.

Table 11. Influence of nitrogen (N) fertilizer rate on the grain yield of rice experimental line ARX7-1084 at the University of Arkansas System Division of Agriculture's Northeast Research and Extension Center (NEREC), Keiser, Ark., Pine Tree Research Station (PTRS), Colt, Ark., and the Rice Research and Extension Center (RREC), Stuttgart, Ark., during 2019.

	Grain Yield		
N Fertilizer Rate	**NEREC**	**PTRS**	**RREC**
(lb N/ac)	**---------- (bu./ac) ----------**		
0	85.2	71.8	125.2
60	----	127.8	169.6
90	172.0	149.1	202.5
120	166.8	158.8	218.6
150	179.4	163.7	235.0
180	191.4	173.8	234.4
210	188.2	----	----
LSD$_{(\alpha=0.05)}$[a]	17.3	17.6	19.8
C.V.[b]	7.0	8.3	6.4

[a] LSD = least significant difference.

[b] C.V. = coefficient of variation.

Table 12. 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), Keiser, Ark., Pine Tree Research Station (PTRS), Colt, Ark., and the Rice Research and Extension Center (RREC), Stuttgart, Ark., during 2019.

	Grain Yield		
N Fertilizer Rate	**NEREC**	**PTRS**	**RREC**
(lb N/ac)	**---------- (bu./ac) ----------**		
0	59.1	94.2	80.9
60	----	159.7	137.6
90	115.3	175.8	168.7
120	150.1	193.9	202.2
150	184.0	210.0	220.5
180	196.8	212.0	226.3
210	206.1	----	----
LSD$_{(\alpha=0.05)}$[a]	12.7	16.3	12.7
C.V.[b]	5.5	6.2	4.9

[a] LSD = least significant difference.

[b] C.V. = coefficient of variation.

Allowable Water Deficit When Utilizing Alternative Rice Irrigation Strategies

*J.L. Chlapecka,[1] J.T. Hardke,[2] T.L. Roberts,[1] D.L. Frizzell,[2] E. Castaneda-Gonzalez,[2] T. Clayton,[2]
K. Hale,[2] T. Frizzell,[2] M. Duren,[3] M. Mann,[3] S. Clark,[4] and A. Ablao[4]*

Abstract

Rice (*Oryza sativa* L.) acres utilizing alternative irrigation practices have increased tremendously over the past several growing seasons, mainly in the form of furrow-irrigated rice (FIR) due in part to its water saving capability and reduced labor requirement. Because this is a new concept for many producers, there is little guidance on producing rice under the FIR and alternate wetting and drying (AWD) systems. A study was initiated in 2018 and continued in 2019 to define the optimum soil moisture threshold for rice produced using furrow-irrigation and AWD production strategies. Large, production-scale trials in both FIR and AWD were conducted at the University of Arkansas System Division of Agriculture's Pine Tree Research Station (PTRS) near Colt, Arkansas on a Calloway silt loam and the Northeast Research and Extension Center (NEREC) near Keiser, Arkansas on a Sharkey silty clay. The timing of irrigation within the FIR treatments was determined based on a soil moisture threshold of either -15, -30, or -45 centibars (cb), while AWD trials utilized the same thresholds but only between 3 weeks after the initial flood establishment and 50% heading. Data from the 2019 growing season suggested that the irrigation threshold did not have a significant influence on rice grain yield under FIR production. However, the control performed better than all FIR at the PTRS, while all FIR performed better than the control at the NEREC. Alternate wetting and drying rice performed equally to the control at the PTRS, but AWD rice with a -15 or -30 cb threshold actually performed better than the -45 cb threshold and the control at the NEREC. The -45 cb threshold also resulted in significant irrigation water savings—17.2% and 34.1% savings in FIR and 17.7% and 73.0% savings in AWD when compared to the control at the PTRS and the NEREC, respectively. These studies suggest that utilizing a -45 cb threshold under alternative irrigation strategies allows for significant water savings while maintaining rice yield and quality.

Introduction

Rice production in Arkansas has traditionally utilized a direct-seeded, delayed-flood system, either with a traditional cascade flood or multiple inlet irrigation. However, approximately 149,000 acres were irrigated using alternative systems in 2019, which represented 13.2% of rice acres (Hardke, pers. comm.). The majority of the transition to alternative irrigation practices has been due to the rise in furrow-irrigated rice (FIR) acres, which have increased from approximately 39,000 to 41,000 acres in 2016 and 2017 to 109,000 acres in 2018 (Hardke, 2019). It has been estimated that FIR acres approached 118,000 in the 2019 growing season (Hardke, pers. comm.). Much like the direct-seeded, delayed-flood system, alternate wetting and drying (AWD) rice has nitrogen (N) applied and a flood established at the 4- to 5-leaf growth stage (V4–V5); however, the flood is allowed to be drawn down and naturally subsides to a predetermined moisture level once the majority of the preflood N is taken up (2 to 3 weeks after N application). The FIR system grows under more upland conditions; however, a tail levee can be constructed to allow excess irrigation water or rainfall to back up into the field—not to exceed 6 to 8 in. in depth. Furrow-irrigated rice also receives an initial N application of a lower rate at V4–V5 but will generally require 2 additional applications prior to reproductive growth (unpublished data).

There are currently no firm guidelines on timing irrigation when utilizing the alternative irrigation strategies of FIR and AWD. Most FIR production is irrigated 1 to 3 times per week, with water application rate and timing dependent on rainfall and a set calendar schedule. A flood is currently recommended to be re-established in AWD rice production when mud appears, which could be a very subjective measure (Henry et al., 2017). Rice grain yield was correlated directly to irrigation application amount in previous studies from Arkansas, Louisiana, Missouri, and Texas (Van Der Hoek, 2001); but the Mississippi River Valley alluvial aquifer (MRVAA) level is declining unsustainably. Proper irrigation timing can help to alleviate issues with water availability while still maintaining rice yield and quality. Trials were conducted at 2 University of Arkansas System Division of Agriculture research stations in 2019 to quantify the allowable water deficit for FIR and AWD production.

Procedures

Both FIR and AWD irrigation trials were conducted at the University of Arkansas System Division of Agriculture's Pine

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[1] Senior Graduate Research Assistant and Associate Professor, respectively, Department of Crop, Soil, and Environmental Science, Fayetteville.

[2] Rice Extension Agronomist, Program Associate, Program Associate, Program Associate, Program Associate, and Program Technician, respectively, Department of Crop, Soil, and Environmental Science, Stuttgart.

[3] Resident Director and Research Technician, respectively, Northeast Research and Extension Center, Keiser.

[4] Resident Director and Research Technician, respectively, Pine Tree Research Station, Colt.

Tree Research Station (PTRS) near Colt, Arkansas (mapped as primarily a Calloway silt loam), and Northeast Research and Extension Center (NEREC) near Keiser, Arkansas (mapped as primarily a Sharkey silty clay).

Furrow-Irrigated Rice

At PTRS, a 30-in. furrow spacing was utilized, and beds were established just prior to planting. A randomized complete block (RCB) design was arranged with 3 replications. Plots were 40 ft (16 rows) in width and 640 ft in length. The hybrid cultivar RT XP753 was drilled on 7.5-in. row spacings at 27 lb seed/ac (12.5 seed/ft^2) on 16 May in an area where soybean (*Glycine max* L.) was grown the previous season. The emergence date was 23 May. The N-STaR program recommended a single pre-flush rate of 150 lb N/ac, which was applied on 15 June via ground application, and the initial irrigation of all treatments was initiated on 18 June. The pre-flush application was intended to be split into multiple applications, but due to application limitations was made in a single application. A late-boot N application of 30 lb N/ac was applied aerially on 5 August. All fertilizer treatments were applied as urea (46% N) treated with the urease inhibitor n-butyl-thiophosphoric triamide (NBPT; Agrotain Ultra, 26.7% NBPT Koch Fertilizer, L.L.C., Wichita, Kan.). All treatments were drained on 5 September, and the first replication was harvested on 20 September, while the last 2 replications were harvested on 27 September due to rain-out.

At NEREC, a 38-in. furrow spacing was utilized, and beds were established 2 weeks prior to planting. A randomized complete block (RCB) design with 3 replications was utilized. Plots were 51 ft (16 rows) in width and 1200 ft in length. The hybrid cultivar RT XP753 was drilled on 7.5-in. row spacings at 30 lb seed/ac (14 seed/ft^2) on 30 April following soybean from the previous growing season. The emergence date was 11 May. Nitrogen fertilizer was applied aerially in 4 split applications—75 lb N/ac on 5 June, 75 lb N/ac on 19 June, 46 lb N/ac on 26 June, and a late-boot application of 30 lb N/ac on 29 July. Over 2 in. of rain was received on 7 June to incorporate the initial N application, so this was counted as the initial irrigation. All treatments were drained on 26 August and harvested on 10 September.

Watermark sensors (Irrometer, Riverside, Calif.) were installed at both sites in the top one-third of the field. Sensors were placed at the top of an interior bed at 4-, 8-, and 12-in. depths. Irrigation timing was determined based on the average of the 4-in. depth sensor reading from the 3 replications. Irrigation triggers for the FIR treatments were -15, -30, and -45 centibars (cb). There were also conventional direct-seeded, delayed-flood checks at both sites, which were flooded to a 2- to 4-in. depth at V4–V5 and maintained through the timing of final irrigation on FIR plots. A flowmeter was installed at each site to quantify the irrigation water applied to each treatment so that no 2 treatments were irrigated simultaneously. Data were analyzed in SAS v. 9.4 using the PROC GLIMMIX procedure (SAS Institute, Inc., Cary, N.C.).

Alternate Wetting and Drying

At PTRS, a RCB design with 3 replications was utilized. Plots were 35 ft wide by 600 ft long and contained 6 equidistant cross-levees, creating 5 paddies. The hybrid cultivar RT XP753 was drilled on 7.5-in. row spacings at 24 lb seed/ac (11 seed/ft^2) on 18 May following soybean from the previous growing season. The emergence date was 24 May. A single preflood N application of 150 lb N/ac was applied on 17 June according to the N-STaR recommendation, and irrigation of all treatments was initiated on 20 June. A late-boot N application of 30 lb N/ac was also applied on 5 August. All plots were drained on 3 September and harvested on 19 September.

At NEREC, a RCB design with 3 replications was also utilized. Plots were 34 ft wide by 550 ft long and contained 6 equidistant cross-levees, creating 5 paddies. The hybrid cultivar RT XP753 was drilled on 7.5-in. row spacings at 27 lb seed/ac (12.5 seed/ft^2) on 30 April following soybean from the previous growing season. The emergence date was 11 May. A single preflood N application of 160 lb N/ac was applied on 5 June according to the N-STaR recommendation, and irrigation of all treatments was initiated on 7 June utilizing a greater than 2-in. rainfall event. A late-boot N application of 30 lb N/ac was also applied on 29 July. All plots were drained on 26 August and harvested on 10 September.

At both sites, the initial flood was maintained for 3 weeks to reduce N loss and optimize N uptake efficiency. The flood was then allowed to naturally subside. Watermark sensors were installed at 4-, 8-, and 12-in. depths in the top paddy. A flood was re-established on each treatment when the 4-in. depth sensor reading reached a predetermined threshold: either -15, -30, or -45 cb. Direct-seeded, delayed-flood checks were also established at both sites, which were flooded to a 2- to 4-in. depth, and the flood was maintained until the recommended drain date. A flowmeter was installed at each site to quantify the amount of irrigation water applied to each treatment so that no 2 treatments were irrigated simultaneously. All measures were analyzed with SAS v. 9.4 and the PROC GLIMMIX procedure (SAS Institute, Inc., Cary, N.C.).

Results and Discussion

Furrow-Irrigated Rice

At PTRS, the direct-seeded, delayed-flood control performed better than all FIR treatments (Table 1). Rice grain yield of the control averaged 26.2 to 31.1 bu./ac higher than all FIR soil moisture thresholds, and head rice averaged 6.3% to 7.8% higher. Canopy height of the control averaged 4.0 to 4.3 in. greater than all FIR, but the number of days to heading was also delayed by an average of 4 days. Harvest moisture was 1.7% to 2.1% higher for the control compared to the -15 and -30 cb FIR thresholds, which coincides with the delay in heading; however, the harvest moisture of the -45 cb treatment did not differ from all other treatments. Additionally, the total white rice percentage did not differ across the -30 and -45 cb FIR thresholds and the control, but the -15 cb threshold did produce 0.4% to 0.5% less total white rice than the -30 and -45 cb thresholds. Test weight did not differ significantly across treatments. Irrigation water use was not analyzed due to a lack of replication; however, irrigation water use did decrease as the allowable soil moisture threshold increased while the control used less irrigation water than the -15 and -30 cb soil moisture thresholds (Table 1).

At NEREC, the opposite trend occurred—that is, all FIR performed better than the control (Table 2). Rice grain yield averaged 19.7 to 29.8 bu./ac greater across all FIR thresholds than the direct-seeded, delayed-flood control. Additionally, the FIR produced 5.1% to 6.6% greater head rice yield. Total white rice percentage was highest with the -15 and -45 cb thresholds, which both yielded a greater percentage than the control. Test weight was greatest with the -45 cb threshold as well as the control, while harvest moisture was greatest with the -30 and -45 cb threshold. Days to heading and canopy height did not differ across treatments. Irrigation water use decreased as soil moisture threshold increased, while the control used the greatest amount of irrigation water (Table 2).

Opposing trends occurred at the 2 FIR sites in 2019. Better yield and quality were achieved with the control flood at PTRS, while NEREC produced exactly the opposite result. One reason for this discrepancy could be that the optimum N management regime was utilized at NEREC while PTRS only received a single preflood N application, which can result in an average yield loss of near 20 bu./ac (unpublished data). It is interesting to note that in 2018, when a single preflood application was received at both sites, the NEREC yield trend was opposite that of 2019 but identical to PTRS 2019 (Chlapecka et al., 2019).

Alternate Wetting and Drying (AWD)

At PTRS, there were few differences among treatments (Table 3). Head rice yield differed slightly and was greatest within the -30 and -45 cb thresholds, although the -15 cb threshold and the control did not differ from the -30 cb threshold. All other measures, including rice grain yield, days to heading, canopy height, harvest moisture, test weight, and total white rice did not differ across AWD soil moisture thresholds or the control. Rice grain yield averaged 226.8 to 245.0 bu./ac, but head rice yield averaged only 30.2% to 34.0%. Irrigation water use was under 15.8 ac-in./ac for all AWD rice, while the control averaged 19.2 ac-in./ac (Table 3).

At NEREC, there were greater differences, including rice grain yield and quality (Table 4). Rice grain yield was greatest within the -15 and -30 cb thresholds, averaging 224.7 and 219.6 bu./ac, respectively. These were both significantly greater than the -45 cb threshold and the control, which yielded 205.1 and 200.7 bu./ac, respectively. This trend continued with head rice yield, which was greater within the -15 and -30 cb thresholds compared to the -45 cb threshold and the control. Total rice was also greatest within the -15 and -30 cb thresholds, averaging 71.0% and 70.8%, respectively. Harvest moisture was 1.0% to 1.4% lower in the control compared to all AWD thresholds, as the control headed 3–5 days earlier than all AWD thresholds. Canopy height and test weight did not differ across treatments. Irrigation water use differed drastically, as the -30 and -45 cb thresholds required 18.8 and 20.3 ac-in./ac less irrigation water, respectively, than the -15 cb threshold. The control required 11.1 ac-in./ac more irrigation water than even the -15 cb threshold, reflecting tremendous water savings when utilizing AWD practices (Table 4).

Practical Applications

Although the 2019 FIR trials had conflicting results when comparing between sites, there is a valid explanation. The control likely yielded greater at the PTRS due to a suboptimum N management scheme for FIR, although the single preflood N application was able to produce optimum yield for FIR in 2018 (Chlapecka et al., 2019). The FIR at the NEREC was also produced under suboptimal N management in 2018, which allowed the control to yield greater than all FIR. Managing the NEREC location FIR under the optimum N strategy in 2019 allowed the FIR to actually yield greater than the control, which falls in line with many 2019 producer yields for early season rice on clay soils in the area.

Finding no differences in yield across AWD thresholds and the control at PTRS was consistent with results from 2018 (Chlapecka et al., 2019); however, the NEREC results did not agree. One possible explanation is that the dry-down period did improve yield similarly to FIR at the NEREC, but the -45 cb threshold was allowed to dry down much further than -45 cb due to irrigation restraints. The soil was allowed to crack, and drought stress likely decreased yield slightly under the -45 cb threshold.

Ultimately, it appears that FIR and AWD are both viable options for utilizing alternative irrigation strategies in rice. Drying down to the -45 cb threshold did not significantly compromise yield or quality when compared to lower soil moisture thresholds, with the exception of AWD at the NEREC, which reached well below -45 cb before the flood could be reapplied. Additionally, drying down to -45 cb decreased water use compared to the control in all trials and sites—from 17.2% to 73.0%. Thus, data suggest that utilizing a -45 cb threshold with alternative irrigation strategies of rice has the potential to produce optimal rice grain yield and quality while saving precious water resources.

Acknowledgments

This research was supported by the rice growers of Arkansas through the Arkansas Rice Check-Off administered by the Arkansas Rice Research and Promotion Board; and the University of Arkansas System Division of Agriculture. The authors also wish to thank additional support staff at the Pine Tree Research Station and Northeast Research and Extension Center—without their support, these studies would not have been possible.

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Table 1. Furrow-irrigated rice trials at the University of Arkansas System Division of Agriculture's Pine Tree Research Station (PTRS) near Colt, Arkansas in 2019.

Soil moisture threshold	Grain yield	Days to heading	Canopy height	Harvest moisture	Test weight	Head rice	Total rice	Irrigation water use
(cb)	(bu./ac)	(d)	(in.)	(%)	(lb/bu.)	----------(%)----------		(ac-in./ac)
-15	171.7 b[†]	78 b	30.2 b	18.2 b	42.0	36.6 b	71.2 b	52.1
-30	171.8 b	78 b	30.4 b	18.6 b	42.2	38.1 b	71.7 a	43.3
-45	166.9 b	78 b	30.5 b	19.0 ab	42.3	37.3 b	71.6 a	31.2
Flood	198.0 a	82 a	34.5 a	20.3 a	42.3	44.4 a	71.3 ab	37.7
P-value	0.0036	<0.0001	0.0150	0.0252	0.7920	0.0089	0.0199	N/A

[†] Means followed by the same letter within a column are not significantly different using a protected least significant difference at α = 0.05. N/A = not available.

Table 2. Furrow-irrigated rice trials at the University of Arkansas System Division of Agriculture's Northeast Research and Extension Center (NEREC) in Keiser, Arkansas in 2019.

Soil moisture threshold	Grain yield	Days to heading	Canopy height	Harvest moisture	Test weight	Head rice	Total rice	Irrigation water use
(cb)	(bu./ac)	(d)	(in.)	(%)	(lb/bu.)	----------(%)----------		(ac-in./ac)
-15	217.3 a	85	34.5	16.9 b	42.3 bc	62.3 a	72.0 a	41.2
-30	227.4 a	85	35.8	18.0 a	41.5 c	60.7 a	70.8 bc	34.2
-45	225.0 a	85	35.2	17.4 ab	42.8 ab	61.5 a	71.6 ab	28.4
Flood	197.6 b	85	32.8	15.1 c	43.5 a	55.6 b	70.4 c	43.1
P-value	0.0003	N/A	0.2347	<0.0001	0.0048	0.0010	0.0042	N/A

[†] Means followed by the same letter within a column are not significantly different using a protected least significant difference at α = 0.05. N/A = not available.

Table 3. Alternate wetting and drying (AWD) rice trials at the University of Arkansas System Division of Agriculture's Pine Tree Research Station (PTRS) near Colt, Arkansas in 2019.

Soil moisture threshold	Grain yield	Days to heading	Canopy height	Harvest moisture	Test weight	Head rice	Total rice	Irrigation water use
(cb)	(bu./ac)	(d)	(in.)	(%)	(lb/bu.)	----------(%)----------		(ac-in./ac)
-15	226.8	76	34.8	15.1	43.6	30.2 b	71.1	12.0
-30	238.8	76	34.4	14.9	43.9	32.8 ab	71.4	10.9
-45	245.0	76	37.4	15.0	43.7	34.0 a	70.8	15.8
Flood	236.1	76	35.7	14.6	43.1	30.4 b	70.8	19.2
P-value	0.0909	N/A	0.5514	0.3019	0.2470	0.0173	0.1689	N/A

† Means followed by the same letter within a column are not significantly different using a protected least significant difference at α = 0.05. N/A = not available.

Table 4. Alternate wetting and drying (AWD) rice trials at the University of Arkansas System Division of Agriculture's Northeast Research and Extension Center (NEREC) in Keiser, Arkansas in 2019.

Soil moisture threshold	Grain yield	Days to heading	Canopy height	Harvest moisture	Test weight	Head rice	Total rice	Irrigation water use
(cb)	(bu./ac)	(d)	(in.)	(%)	(lb/bu.)	----------(%)----------		(ac-in./ac)
-15	224.7 a	83	35.4	16.6 a	43.2	60.6 a	71.0 a	31.9
-30	219.6 a	84	35.0	16.2 a	43.4	59.8 a	70.8 ab	13.1
-45	205.1 b	85	32.4	16.4 a	42.9	57.4 b	70.2 c	11.6
Flood	200.7 b	80	32.8	15.2 b	43.4	56.0 b	70.4 bc	43.0
P-value	0.0030	N/A	0.7338	0.0010	0.2137	0.0006	0.0236	N/A

† Means followed by the same letter within a column are not significantly different using a protected least significant difference at α = 0.05. N/A = not available.

Evaluation of SuperU® as a Nitrogen Source in Furrow-Irrigated Rice Production

*J.L. Chlapecka,[1] J.T. Hardke,[2] T.L. Roberts,[1] D.L. Frizzell,[2] E. Castaneda-Gonzalez,[2]
T. Clayton,[2] K. Hale,[2] T. Frizzell,[2] and M.J. Lytle[1]*

Abstract

Furrow-irrigated rice (FIR) (*Oryza sativa* L.) acreage has steadily increased over the past several growing seasons, and it appears this trend will continue. One issue that is likely to be common in FIR is the possible loss of nitrogen (N) via nitrification-denitrification sequences in the alternating aerobic-anaerobic soil conditions. Trials were established in 2019 at 1 commercial site, Almyra, on a Dewitt silt loam and at 2 University of Arkansas System Division of Agriculture research stations, the Pine Tree Research Station (PTRS) on a Calloway silt loam and the Rice Research and Extension Center (RREC) on a Dewitt silt loam. Factors included location within the field (top and bottom), N source [urea + n-butyl thiophosphoric triamide (NBPT) and SuperU®], and N management regime, of which there were six variations of rate and time combinations. The use of SuperU® increased yield at the PTRS by 17.7 bu./ac at the bottom of the field compared to urea + NBPT, but did not affect yield at the top of the field nor did it have an effect at the other two sites. The major yield discrepancy was at Almyra, where the bottom of the field yielded 57.6 bu./ac greater than the top of the field, most likely due to drought stress at the top of the field. Nitrogen source did not affect head rice yield or total white rice yield at any of the locations. Considering current pricing and trial results, urea + NBPT appears to be the optimum N source for furrow-irrigated rice production in Arkansas.

Introduction

Only around 40,000 acres or less utilized the furrow-irrigated rice (FIR) system in Arkansas in 2017 and prior growing seasons; however in 2018, acres exceeded 109,000, and 2019 acres have been estimated near 118,000 (Hardke, 2019; Hardke, pers. comm.). Limited work has been done on the nitrogen (N) management of FIR, but most was completed prior to the introduction of hybrid rice technology to the United States. Hybrid rice cultivars have greater disease resistance packages and larger root systems than pure-line varieties, making them advantageous for FIR production. Hybrid rice cultivars also have an increased ability to take up native soil N compared to pure-line varieties (Norman et al., 2013). The current recommendation for FIR production on a shallow slope (0.1 ft/100 ft or less) includes a 100% preflood (PF) application of urea at the 4- to 5-leaf stage (V4–V5) followed by an additional 100 lb urea/ac on the upper end of the field 14 days later. A 50-50 split of PF N 10 days apart, followed by an additional 100 lb urea/ac 7–10 days later, is recommended for a steeper slope (0.1 ft/100 ft or greater) (Hardke et al., 2017). Hardke et al. (2017) also suggest a spoon-feed approach of four to five 100 lb urea/ac applications in one-week intervals for certain situations. However, it is noted that guidelines are based primarily on observation with little testing to support management practices.

SuperU® (Koch Fertilizer LLC., Wichita, Kan.) is a urea-based product which is impregnated with both a urease inhibitor, n-butyl-thiophosphoric triamide (NBPT), and a nitrification inhibitor, dicyandiamide (DCD). The product has claims of increased yield when applied to FIR. Approximately 81% of rice acres utilized an NBPT product to minimize ammonia volatilization losses in 2018 (Hardke, 2019). Nitrification is typically not an issue in direct-seeded, delayed-flood rice production because oxygen is essential for this N transformation process, which is severely lacking in a conventionally flooded rice environment. However, nitrification will inevitably be an issue in FIR, especially on lighter soil textures due to the fact that the majority of the field will remain aerated. Trials were conducted within 3 FIR fields in 2019 to evaluate the usefulness of SuperU® in the FIR system.

Procedures

Furrow-irrigated rice N management trials were established at 1 commercial farm and 2 University of Arkansas System Division of Agriculture research stations in 2019. The commercial site was located south of Alymra, Arkansas on a Dewitt silt loam (Fine, smectitic, thermic Typic Albaqualfs) (Soil Survey Staff, 2019). The 2 research station locations were the Pine Tree Research Station (PTRS) located near Colt, Arkansas on a Calloway silt loam (fine-silty, mixed, active, thermic Aquic Fraglossudalfs) and the Rice Research and Extension Center (RREC) located near Stuttgart, Arkansas on a Dewitt silt loam (Fine, smectitic, thermic Typic Albaqualfs).

At all locations, beds with a 30-in. furrow spacing were established prior to planting. The small plot design was a randomized complete block (RCB) with 4 replications. At Almyra and the PTRS locations, trials were placed in both the top third and bottom third of the field to compare drier and more saturated soil

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

[2] Rice Extension Agronomist, Program Associate, Program Associate, Program Associate, Program Associate, and Program Technician, respectively, Department of Crop, Soil, and Environmental Sciences, Stuttgart.

conditions. At RREC, there was only room for one test area with 5 replications. Each plot was three beds (7.5 ft) in width and 17 ft in length. Approximately an 8- to 10-in. flood was held at the bottom of the field at Almyra, a 1- to 3-in. flood was held at the bottom of the field at RREC, and no flood was held at PTRS due to the natural slope of the field. The hybrid cultivar RT XP753 was grown at all locations and the previous crop was soybean [*Glycine max* (L.) Merr.]. The N-STaR program recommended preflood (PF) rate was utilized to determine the base season total N rate for each treatment—100 lb N/ac at Almyra, 150 lb N/ac at PTRS, and 120 lb N/ac at RREC (Tables 1–3). Nitrogen applications were applied in weekly intervals where week 1 corresponded to a PF application (V4–V5), and week 4 corresponded to approximately green ring. Nitrogen applications are denoted by all 4 weekly application rates as (Week 1, Week 2, Week 3, and Week 4) in lb N/ac. Applications began on 28 May at Almyra, 15 June at PTRS, and 19 June at RREC. Total N uptake samples were taken at 50% heading from a 3-ft section of a bordered non-harvest row—25 July at Almyra, 13 August at PTRS, and 14 August at RREC. The 50% heading stage is relatively easy to identify, and maximum fertilizer N recovery has occurred at this growth stage (Norman et al., 1992). Harvest occurred on 13 September at Almyra, 19 September at PTRS, and 2 October at RREC.

Field management other than N fertilization was consistent with University of Arkansas System Division of Agriculture recommendations. The interval between irrigations averaged once per week at Almyra and twice per week at PTRS and RREC. A split-plot design (top and bottom of field) with a two-factor factorial was utilized with N source being one factor (urea + NBPT and SuperU®) and application timing being the second factor, which ranged from a single PF application to a four-way split application (Tables 1–3). Measures included normalized difference vegetative index (NDVI) using Greenseeker (Trimble Inc., Sunnyvale, Calif.) at green ring (R0), heading date, total N uptake, canopy height, harvest moisture, test weight, rice grain yield, and milling yield. All measures were analyzed with PROC GLIMMIX using SAS v. 9.4 (SAS Institute, Inc. Cary, N.C.).

Results and Discussion

At Almyra, rice grain yield was much greater at the bottom of the field, where a flood was present, compared to the top of the field, which was grown in upland fashion ($P = 0.0002$). Rice grain yield averaged 224.8 bu./ac at the bottom of the field and 166.0 bu./ac at the top of the field, which was likely due to the fact that water was not able to fully saturate beds at the top of the field. Irrigation events lasting over 50 hours were attempted without success of saturating completely through the beds. The nitrogen source or regime did not affect rice grain yield. Head rice yield was 1.2% greater when SuperU® was used as opposed to urea + NBPT ($P = 0.0462$) and was 26.0% greater at the bottom of the field compared to the top ($P = 0.0244$), but did not differ by N management regime. Total white rice yield was actually 0.8% greater at the top of the field ($P < 0.0001$), but did not differ by N management regime or N source. Additional plant and yield data can be found in Tables 4 and 7.

At PTRS, there was a location × source interaction, as SuperU® actually produced 17.7 bu./ac greater rice grain yield at the bottom of the field compared to urea + NBPT ($P = 0.0303$). The nitrogen regime did not affect rice grain yield. Head rice yield averaged 6.7% greater at the top of the field compared to the bottom ($P < 0.0001$) and also differed by N regime ($P = 0.0003$). The 75-0-75-46 (Treatment 7) split regime produced at least 3.5% greater head rice yield than all other regimes. Head rice yield was not affected by N source. Total white rice yield was not affected by N source or regime or location within the field. Additional plant and yield data can be found in Tables 5 and 8.

At RREC, rice grain yield was not affected by N source or regime. However, head rice yield was affected by the N regime ($P = 0.0033$). The 63-0-63-46 (Treatment 7) and 125-0-0-0 (Treatment 2) N regimes produced the greatest head rice yield, 40.7% and 38.1%, respectively. Total white rice yield was also affected by the N regime ($P = 0.0154$). The 63-0-63-46 (Treatment 7), 125-0-0-0 (Treatment 2), and 63-0-63-0 (Treatment 3) N regimes produced the highest total white rice yield at 70.4%, 70.2%, and 69.8%, respectively. Additional plant and yield data can be found in Tables 6 and 9.

Practical Applications

Similar to results in 2018, utilizing SuperU® as a N source had little benefit over urea + NBPT (Chlapecka et al., 2019). At PTRS using SuperU® did provide a 17.7 bu./ac rice grain yield advantage at the bottom of the field where more wetting and drying occurred, but no flood was held. But yield was not affected at the top of the field nor at the other two sites. The relatively small fraction of DCD, which works as a nitrification inhibitor in SuperU®, could be one reason that the product did not provide a consistent benefit. It has been reported that the proprietary blend contains 0.85% DCD. However, further work on the use of SuperU® in FIR on soils similar to those at PTRS could be of significance.

Acknowledgments

This research was supported by the rice growers of Arkansas from the Arkansas Rice Check-Off funds administered by the Arkansas Rice Research and Promotion Board; and the University of Arkansas System Division of Agriculture. Partial funding was also provided by Koch Fertilizer, LLC. The authors also express thanks to producer cooperators at the on-farm research sites and Ali Ablao at PTRS, who helped make this research possible.

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Table 1. Furrow-irrigated rice nitrogen (N) management treatments at Almyra, Arkansas in 2019.

Treatment Number	Total N Rate	N Source	Week 1 Preflood	Week 2	Week 3	Week 4
	(lb/ac)		--------------------(lb N/ac)--------------------			
2	100	Urea + NBPT	100	-	-	-
3	100		50	-	50	-
4	100		50	25	25	-
5	100		25	25	50	-
6	100		25	25	25	25
7	146		50	-	50	46
2	100	SuperU®	100	-	-	-
3	100		50	-	50	-
4	100		50	25	25	-
5	100		25	25	50	-
6	100		25	25	25	25
7	146		50	-	50	46

Table 2. Furrow-irrigated rice nitrogen (N) management treatments at the University of Arkansas System Division of Agriculture's Pine Tree Research Station (PTRS) near Colt, Arkansas in 2019.

Treatment Number	Total N Rate	N Source	Week 1 Preflood	Week 2	Week 3	Week 4
	(lb/ac)		--------------------(lb N/ac)--------------------			
2	150	Urea + NBPT	150	-	-	-
3	150		75	-	75	-
4	150		75	38	38	-
5	150		38	38	75	-
6	150		38	38	38	38
7	196		75	-	75	46
2	150	SuperU®	150	-	-	-
3	150		75	-	75	-
4	150		75	38	38	-
5	150		38	38	75	-
6	150		38	38	38	38
7	196		75	-	75	46

Table 3. Furrow-irrigated rice nitrogen (N) management treatments at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC) near Stuttgart, Arkansas in 2019.

Treatment Number	Total N Rate	N Source	Week 1 Preflood	Week 2	Week 3	Week 4
	(lb/ac)		-------------------(lb N/ac)-------------------			
2	125	Urea + NBPT	125	-	-	-
3	125		63	-	63	-
4	125		63	31	31	-
5	125		31	31	63	-
6	125		31	31	31	31
7	171		63	-	63	46
2	125	SuperU®	125	-	-	-
3	125		63	-	63	-
4	125		63	31	31	-
5	125		31	31	63	-
6	125		31	31	31	31
7	171		63	-	63	46

Table 4. Rice response to nitrogen (N) source and management regime at Almyra, Arkansas in 2019.

N Source	N Regime	NDVI[†]	Heading Date	Canopy height	N Uptake
	Wk 1-2-3-4			(in.)	(lb N/ac)
Urea + NBPT	100-0-0-0	0.71	25 July	31.8	159.6 de[‡]
	50-0-50-0	0.74	25 July	31.5	175.1 bcde
	50-25-25-0	0.71	25 July	31.0	157.8 de
	25-25-50-0	0.73	25 July	31.8	143.2 e
	25-25-25-25	0.73	25 July	31.7	209.0 ab
	50-0-50-46	0.75	26 July	32.0	234.5 a
SuperU®	100-0-0-0	0.71	25 July	31.9	202.2 abc
	50-0-50-0	0.74	25 July	32.7	187.1 bcd
	50-25-25-0	0.73	25 July	31.7	165.2 cde
	25-25-50-0	0.73	25 July	31.5	191.9 abcd
	25-25-25-25	0.72	25 July	32.3	174.4 bcde
	50-0-50-46	0.75	26 July	33.5	215.9 ab
	P-value	0.8993	0.7262	0.2624	0.0264

[†] NDVI, Normalized difference vegetative index.

[‡] Means followed by the same letter within a column are not significantly different using a protected least significant difference at α = 0.05.

Table 5. Rice response to nitrogen (N) source and management regime at the University of Arkansas System Division of Agriculture's Pine Tree Research Station (PTRS) near Colt, Arkansas in 2019.

N Source	N Regime	NDVI†	Heading Date	Canopy height	N Uptake
	Wk 1-2-3-4			(in.)	(lb N/ac)
Urea + NBPT	150-0-0-0	0.73	11 Aug	30.7	126.8
	75-0-75-0	0.77	11 Aug	30.4	158.5
	75-38-38-0	0.76	11 Aug	30.4	156.3
	38-38-75-0	0.75	11 Aug	31.3	163.8
	38-38-38-38	0.75	11 Aug	31.1	169.1
	75-0-75-46	0.75	12 Aug	32.1	169.5
SuperU®	150-0-0-0	0.74	11 Aug	29.4	161.2
	75-0-75-0	0.76	12 Aug	31.9	149.2
	75-38-38-0	0.76	12 Aug	31.2	155.5
	38-38-75-0	0.75	11 Aug	31.7	123.5
	38-38-38-38	0.76	12 Aug	31.7	131.5
	75-0-75-46	0.75	13 Aug	31.6	138.4
	P-value	0.9375	0.8419	0.4521	0.2101

† NDVI, Normalized difference vegetative index.

Table 6. Rice response to nitrogen (N) source and management regime at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC) near Stuttgart, Arkansas in 2019.

N Source	N Regime	NDVI†	Heading Date	Canopy height	N Uptake
	Wk 1-2-3-4			(in.)	(lb N/ac)
Urea + NBPT	125-0-0-0	0.75	12 Aug	30.8	149.9
	63-0-63-0	0.74	11 Aug	29.8	134.3
	63-31-31-0	0.75	13 Aug	29.4	127.9
	31-31-63-0	0.76	11 Aug	29.8	137.5
	31-31-31-31	0.77	11 Aug	29.6	147.3
	63-0-63-46	0.74	13 Aug	30.8	177.9
SuperU®	125-0-0-0	0.79	11 Aug	30.9	104.8
	63-0-63-0	0.75	12 Aug	31.4	137.6
	63-31-31-0	0.78	11 Aug	31.1	114.0
	31-31-63-0	0.70	12 Aug	30.4	112.5
	31-31-31-31	0.71	12 Aug	29.3	144.7
	63-0-63-46	0.73	13 Aug	31.8	132.4
	P-value	0.1177	0.0970	0.7282	0.6027

† NDVI, Normalized difference vegetative index.

Table 7. Rice yield response to nitrogen (N) source and management regime at Almyra, Arkansas in 2019.

N Source	N Regime	Rice Grain Yield	Harvest Moisture	Test Weight	Head Rice	Total Rice
	Wk 1-2-3-4	(bu./ac)	(%)	(lb/bu.)	----------(%)----------	
Urea + NBPT	100-0-0-0	192.9	11.7	41.8	32.8	71.3
	50-0-50-0	188.6	11.7	41.6	30.4	71.4
	50-25-25-0	190.5	11.1	42.2	31.1	71.4
	25-25-50-0	191.3	11.4	42.0	30.7	71.5
	25-25-25-25	186.0	11.2	42.1	31.6	71.4
	50-0-50-46	192.8	11.6	41.7	33.2	71.7
SuperU®	100-0-0-0	190.8	11.0	42.3	30.6	71.1
	50-0-50-0	193.5	11.5	41.8	33.1	71.3
	50-25-25-0	188.8	11.2	42.1	31.7	71.1
	25-25-50-0	194.8	11.2	42.0	32.8	71.3
	25-25-25-25	211.2	11.5	41.9	34.2	71.6
	50-0-50-46	198.5	11.4	41.9	34.6	71.7
	P-value	0.2681	0.3726	0.5060	0.1587	0.8621

Table 8. Rice yield response to nitrogen (N) source and management regime at the University of Arkansas System Division of Agriculture's Pine Tree Research Station (PTRS) near Colt, Arkansas in 2019.

N Source	N Regime	Rice Grain Yield	Harvest Moisture	Test Weight	Head Rice	Total Rice
	Wk 1-2-3-4	(bu./ac)	(%)	(lb/bu.)	----------(%)----------	
Urea + NBPT	150-0-0-0	193.5	14.8	39.9	45.1	71.0
	75-0-75-0	184.4	16.3	39.0	46.3	70.6
	75-38-38-0	189.1	15.4	39.6	42.7	70.2
	38-38-75-0	191.2	16.3	39.1	46.1	70.2
	38-38-38-38	200.1	15.9	39.4	48.8	70.5
	75-0-75-46	182.1	16.8	38.9	49.6	70.7
SuperU®	150-0-0-0	188.4	14.8	39.9	42.8	70.4
	75-0-75-0	194.9	15.0	39.9	46.6	70.5
	75-38-38-0	198.9	15.7	39.5	48.1	70.6
	38-38-75-0	193.1	16.0	39.2	45.8	70.3
	38-38-38-38	200.8	15.2	39.8	46.3	70.6
	75-0-75-46	215.3	16.6	39.1	52.6	71.0
	P-value	0.1160	0.6010	0.4913	0.0645	0.3097

Table 9. Rice yield response to nitrogen (N) source and management regime at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC) near Stuttgart, Arkansas in 2019.

N Source	N Regime	Rice Grain Yield	Harvest Moisture	Test Weight	Head Rice	Total Rice
	Wk 1-2-3-4	(bu./ac)	(%)	(lb/bu.)	----------(%)----------	
Urea + NBPT	125-0-0-0	174.4	11.8	52.2	40.6	70.5
	63-0-63-0	153.5	11.0	52.5	31.5	69.7
	63-31-31-0	168.1	12.3	51.4	36.7	69.8
	31-31-63-0	154.3	11.6	52.3	32.6	69.7
	31-31-31-31	157.9	12.1	51.6	33.1	69.7
	63-0-63-46	159.0	11.9	52.0	41.1	70.3
SuperU®	125-0-0-0	168.1	11.7	52.2	35.5	69.9
	63-0-63-0	176.6	12.0	51.9	37.0	70.0
	63-31-31-0	168.3	12.0	51.9	33.8	69.2
	31-31-63-0	150.7	11.7	52.2	33.0	69.3
	31-31-31-31	158.9	12.3	51.5	33.0	69.6
	63-0-63-46	166.6	13.3	50.5	40.3	70.4
	P-value	0.6218	0.2664	0.4182	0.2499	0.6434

2019 Degree-Day 50 (DD50) Thermal Unit Thresholds for New Rice Cultivars and Seeding Date Studies

T.L. Clayton,[1] J.T. Hardke,[1] D.L. Frizzell,[1] R.J. Norman,[2] W.J. Plummer,[3]
K. F. Hale,[1] T.D. Frizzell,[1] A. Ablao,[4] K.A.K Moldenhauer,[1] and X. Sha[1]

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. 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 2019 season, DD50 thermal unit accumulation, developmental data, and the effect of seeding date (SD) on grain and milling yield potential for 20 cultivars were evaluated over six 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 20 cultivars at each location.

Introduction

The Degree-Day 50 (DD50) is an outgrowth of the growing degree-day concept where daily high and low air temperatures are used to determine a day's thermal quality for plant growth. Conceived in the 1970s as a tool to time midseason nitrogen (N) applications, the DD50 computer program has grown into a management aid that provides predicted dates for timing 26 key management decisions including fertilization, pesticide applications, permanent flood establishment, times for scouting insect and disease, predicted draining date and suggested harvest time (Hardke and Norman, 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 elongation (BIE), half-inch internode elongation (0.5-in. IE), 50% heading, drain date, and 20% grain moisture (Hardke and Norman, 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 2019 DD50 study was conducted at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC) near Stuttgart on a DeWitt silt loam soil, and the Pine Tree Research Station (PTRS) near Colt on a Calloway silt loam soil. Twelve pure-line cultivars (ARoma 17, CL153, CL272, CLL15, CLL16, CLM04, Diamond, Jewel, Jupiter, Lynx, PVL01, and Titan) were dry-seeded at a rate of 35 seed/ft^2 in plots 8 rows wide (7.5-in. spacing) and 16.5 ft long, and 8 hybrids (RT CLXL745, RT Gemini 214 CL, RT XP753, RT 3201, RT 7301, RT 7321 FP, RT 7501, RT 7521 FP) were seeded into plots of the same dimensions using the reduced seeding rate for hybrids (12.1 seeds/ft^2). The SDs for 2019 were 21 March, 3 April, 16 April, 29 April, 17 May, and 4 June for RREC, and 2 April, 24 April, 8 May, 28 May, and 12 June for PTRS. Standard

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[1] Program Associate, Rice Extension Agronomist, Program Associate, Program Associate, Program Technician, Professor, and Professor, respectively, Department of Crop, Soil, and Environmental Sciences, Stuttgart.

[2] Professor, Department of Crop, Soil, and Environmental Sciences, Fayetteville.

[3] Program Associate, Department of Entomology and Pathology, Lonoke.

[4] Program Technician, Pine Tree Research Station, Colt.

cultural practices were followed according to the University of Arkansas System Division of Agriculture recommendations. A single preflood nitrogen (N) application of 130 lb N/ac was applied to all plots 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-in. internode elongation was also collected for the 21 March, 16 April, and 17 May at the RREC location. At maturity, the four 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/ac (bu./ac) basis. The dry rice was milled to obtain data on the 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.

Results and Discussion

The amount of time between seeding and emergence ranged from 4 to 18 days at PTRS and 5 to 18 days at 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 2019 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 the establishment of permanent flood followed the same trend as the SD was delayed, ranging from 52 days for the 2 April to 29 for the 12 June SDs at PTRS and 56 days for the 21 March to 24 for the 4 June SDs at RREC. The times from emergence to flooding in 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 2018 (Castaneda-Gonzalez et al., 2019). The cultivars PVL01 and RT 7321 FP required the fewest days and DD50 units to reach 0.5-in. IE with 56 and 55 days, respectively, and 1347 and 1324 DD50 units, respectively. ARoma 17 and Lynx required the most days and DD50 units to reach 0.5-in. IE with 65 and 68 days, respectively, and 1609 and 1694 DD50 units, respectively. The average days to 0.5-in. IE across planting dates was 60, and the average DD50 units across planting dates was 1467.

The time needed to reach the developmental stage known as 50% heading from the time of emergence across SDs and cultivars was 84 at RREC and 78 at PTRS (Tables 4 and 5). The time for cultivars to reach 50% heading ranged from 71 to 101 days at RREC and from 68 to 92 days at PTRS across SDs. For individual cultivars, the time required to reach 50% heading ranged from 101 days for ARoma 17 to 71 days for RT 3201, RT 7321 FP, RT CLXL745, and Titan at RREC. For PTRS, the days to 50% heading ranged from 92 days for CLL16, CLM04, Jupiter, and Lynx to 68 days for RT 3201, RT 7301, RT 7321 FP, RT CLXL745, RT XP753, and Titan. For 2019, the thermal unit accumulation from emergence to 50% heading averaged 2227 DD50 units at RREC and 2181 DD50 units at PTRS. The individual cultivar thermal unit accumulation from emergence to 50% heading ranged from 2028 DD50 units for RT 7301 and RT 7321 FP to 2428 DD50 units for ARoma 17 at RREC. For PTRS, thermal unit accumulation from emergence to 50% heading ranged from 1990 DD50 units for RT 7321 FP to 2359 DD50 units for ARoma 17. The lowest average thermal unit accumulation was the June 4 planting at RREC and May 15 at PTRS.

The average grain yield for 2019 at RREC was 221 bu./ac and 185 bu./ac at PTRS across SDs (Tables 6 and 7). The highest average grain yield across all cultivars was the 20 April SD at RREC and the 5 April SD at PTRS. Lynx was the highest yielding variety at both locations and the hybrids RT 7501, and RT 7521 FP yielded the highest at RREC and PTRS, respectively.

The milling yields for 2019, averaged across SDs and cultivars, were 62/70 (%HR/%TR) at RREC and 59/69 (Tables 8 and 9). The milling yields were consistent for all the SDs but dropped for the 15 May SD at RREC. The PTRS milling was highest for the 5 April SD. This data differs from 2018 when the milling yield at RREC increased for the mid-May SD (Castaneda-Gonzalez et al., 2019).

Practical Applications

The data obtained during 2019 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.

Acknowledgments

The research was funded by Arkansas rice growers through the Arkansas Rice Check-Off funds administered by the Arkansas Rice Research and Promotion Board; and the University of Arkansas System Division of Agriculture. Special thanks are also given to Emmett C. “Chuck” Pipkins for his dedication to making the DD50 Program possible.

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Table 1. General seeding, seedling emergence, and flooding date information for the Degree-Day 50 seeding date study in 2019 at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center, Stuttgart, Arkansas.

	Seeding Date					
Parameter	**21 March**	**3 April**	**16 April**	**29 April**	**17 May**	**4 June**
Emergence date	9 April	18 April	28 April	8 May	23 May	10 June
Flood date	17 May	24 May	1 June	12 June	14 June	29 June
Days from seeding to emergence	18	14	11	8	5	5
Days from seeding to flooding	56	50	45	43	27	24
Days from emergence to flooding	37	35	33	34	21	18

Table 2. General seeding, seedling emergence, and flooding date information for the Degree-Day 50 seeding date study in 2019 at the University of Arkansas System Division of Agriculture's Pine Tree Research Station, near Colt, Arkansas.

	Seeding Date				
Parameter	**2 April**	**24 April**	**8 May**	**28 May**	**12 June**
Emergence date	21 April	5 May	19 May	3 June	17 June
Flood date	25 May	6 June	15 June	5 July	12 July
Days from seeding to emergence	18	10	10	5	4
Days from seeding to flooding	52	42	37	38	29
Days from emergence to flooding	33	31	26	32	24

Table 3. Influence of seeding date on Degree-Day 50 (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, Stuttgart, Arkansas, during 2019.

	Seeding Date							
	21 March		20 April		15 May		Average	
Cultivar	**days**	**DD50 units**	**Days**	**DD50 units**	**days**	**DD50 units**	**days**	**DD50 units**
ARoma 17	79	1740	64	1604	52	1484	65	1609
CLL15	71	1497	56	1355	45	1270	57	1374
CLL16	73	1563	67	1456	47	1325	62	1448
CLM04	76	1670	64	1590	51	1451	64	1570
Diamond	76	1663	61	1521	49	1381	62	1522
Jewel	77	1683	63	1571	51	1451	64	1568
Lynx	82	1840	67	1676	55	1561	68	1694
PVL01	70	1477	56	1371	43	1193	56	1347
RT 3201	72	1534	57	1407	46	1278	58	1406
RT 7321 FP	70	1471	55	1340	42	1162	55	1324
RT 7521 FP	72	1549	57	1407	44	1223	58	1393
RT 7301	72	1534	56	1371	44	1223	58	1388
RT 7501	73	1582	60	1479	47	1326	59	1451
Mean	74	1599	60	1469	47	1333	60	1467
LSD$_{(\alpha = 0.05)}$[a]	2.3	66.0	6.7	72.6	1.9	56.3	NS[b]	100.4

[a] LSD = least significant difference.

[b] NS = not significant.

Table 4. Influence of seeding date on Degree-Day 50 (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, Stuttgart, Arkansas, during 2019.

	Seeding Date													
	21 March		5 April		20 April		2 May		15 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	101	2383	90	2336	87	2284	89	2428	77	2201	74	2157	86	2281
CL153	97	2293	90	2265	86	2258	87	2363	78	2216	75	2173	85	2253
CL272	96	2249	88	2320	86	2258	86	2341	78	2225	74	2149	84	2229
CLL15	95	2219	86	2344	85	2211	87	2370	76	2154	73	2110	83	2197
CLL16	98	2298	90	2209	87	2291	89	2444	79	2267	77	2244	87	2293
CLM04	97	2293	90	2273	87	2279	88	2392	80	2289	78	2258	87	2291
Diamond	98	2299	88	2273	85	2234	87	2363	76	2162	74	2149	84	2227
Jewel	97	2293	89	2177	86	2256	89	2421	78	2223	74	2157	85	2258
Jupiter	100	2354	92	2320	87	2286	87	2370	78	2232	78	2250	87	2297
Lynx	100	2368	91	2130	87	2291	88	2407	82	2334	78	2265	88	2321
PVL01	100	2375	93	2344	90	2360	90	2459	79	2260	78	2251	88	2335
RT 3201	91	2104	84	2225	79	2042	80	2159	71	2028	70	2016	79	2066
RT 7301	97	2290	87	2321	84	2195	85	2311	74	2094	72	2078	84	2189
RT 7321 FP	94	2207	85	2336	82	2141	84	2336	71	2028	71	2063	81	2143
RT 7501	99	2348	89	2169	86	2241	88	2406	77	2193	76	2208	85	2262
RT 7521 FP	97	2291	88	2241	84	2179	87	2385	76	2170	78	2258	85	2240
RT CLXL745	93	2167	85	2130	81	2104	82	2216	71	2028	72	2071	81	2112
RT Gemini 214 CL	97	2272	89	2257	86	2265	88	2414	76	2177	80	2308	86	2272
RT XP753	96	2250	87	2146	83	2172	84	2296	72	2049	72	2086	82	2163
Titan	93	2167	85	2123	80	2084	81	2201	72	2050	71	2063	80	2110
Mean	97	2275	88	2247	85	2221	86	2354	76	2169	75	2166	84	2227
LSD$_{(\alpha = 0.05)}$[a]	2	72	2	33	1	41	2	59	1	36	1	31	4	47

[a] LSD = least significant difference.

Table 5. Influence of seeding date on Degree-Day 50 (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, near Colt, Arkansas, during 2019.

	Seeding Date											
	2 April		24 April		8 May		28 May		12 June		Average	
Cultivar	days	DD50 units	days	DD50 units	days	DD50 Units	days	DD50 Units	days	DD50 Units	days	DD50 Units
ARoma 17	91	2359	83	2243	75	2120	76	2173	72	2136	79	2206
CL153	90	2327	85	2287	77	2192	76	2173	72	2136	80	2223
CL272	91	2364	83	2243	73	2076	75	2149	73	2148	79	2196
CLL15	89	2289	83	2243	75	2120	75	2149	69	2049	78	2170
CLL16	92	2396	89	2420	75	2120	80	2308	76	2246	82	2298
CLM04	92	2396	83	2243	77	2176	77	2197	79	2332	81	2269
Diamond	86	2215	83	2243	76	2148	75	2149	71	2107	78	2172
Jewel	91	2359	87	2353	71	2026	77	2197	70	2078	79	2202
Jupiter	92	2380	83	2243	76	2148	78	2252	75	2210	81	2247
Lynx	92	2369	83	2232	77	2192	77	2220	76	2241	81	2256
PVL01	92	2380	89	2420	77	2192	77	2197	76	2246	82	2287
RT 3201	83	2130	77	2086	72	2048	68	1937	68	2021	74	2044
RT 7301	85	2172	82	2210	75	2137	75	2149	68	2021	77	2138
RT 7321 FP	83	2130	79	2154	72	2120	70	1990	68	2021	75	2083
RT 7501	85	2172	83	2243	69	1960	76	2173	73	2161	77	2142
RT 7521 FP	85	2193	83	2243	77	2192	75	2149	69	2049	78	2165
RT CLXL745	83	2130	79	2131	76	2164	73	2073	68	2021	76	2104
RT Gemini 214 CL	87	2231	83	2243	74	2104	79	2260	71	2107	79	2189
RT XP753	84	2151	81	2193	74	2107	75	2149	68	2021	76	2124
Titan	86	2215	79	2176	75	2120	70	1990	68	2021	76	2104
Mean	88	2269	83	2242	75	2123	75	2152	71	2118	78	2181
LSD$_{(\alpha = 0.05)}$[a]	2	74	2	47	NS[b]	NS	3	91	3	2	4	64

[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, Stuttgart, Arkansas, during 2019.

Cultivar	Grain Yield by Seeding Date						
	21 March	5 April	20 April	2 May	15 May	4 June	Average
	---bu./acre---						
ARoma 17	201	186	178	171	151	157	174
CL153	226	224	202	188	177	176	199
CL272	232	220	236	192	192	188	209
CLL15	222	222	220	193	173	177	201
CLL16	244	255	231	226	211	194	227
CLM04	230	209	226	208	197	180	208
Diamond	233	235	223	220	205	201	220
Jewel	222	222	219	211	205	195	212
Jupiter	248	244	238	227	210	198	226
Lynx	253	243	225	231	213	203	228
PVL01	199	194	187	179	164	161	180
RT 3201	219	222	225	212	198	180	209
RT 7301	265	258	258	261	222	221	248
RT 7321 FP	237	251	256	257	240	227	244
RT 7501	265	263	277	265	250	224	257
RT 7521 FP	230	240	253	232	229	206	232
RT CLXL745	203	231	226	224	224	201	218
RT Gemini 214 CL	250	260	271	243	248	203	246
RT XP753	259	251	271	264	252	233	255
Titan	239	226	230	217	208	207	221
Mean	234	232	235	222	208	197	221
$LSD_{(\alpha = 0.05)}$[a]	18	22	25	18	15	14	12

[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 Rice Research and Extension Center, Stuttgart, Arkansas, during 2019.

Cultivar	Grain Yield by Seeding Date					Average
	2 April	24 April	8 May	28 May	12 June	
	bu./acre					
ARoma 17	155	198	166	157	143	164
CL153	134	178	164	143	125	149
CL272	123	207	183	138	131	160
CLL15	163	237	202	167	162	185
CLL16	169	230	204	183	157	188
CLM04	167	208	210	184	163	186
Diamond	159	236	199	186	165	189
Jewel	160	215	185	165	144	174
Jupiter	159	231	210	188	182	194
Lynx	199	245	227	185	170	206
PVL01	149	180	165	147	126	153
RT 3201	171	208	192	164	164	180
RT 7301	161	259	210	174	158	192
RT 7321 FP	157	266	215	173	169	196
RT 7501	176	234	197	178	193	196
RT 7521 FP	175	245	227	215	196	212
RT CLXL745	147	231	207	158	156	184
RT Gemini 214 CL	171	255	214	200	191	206
RT XP753	175	266	218	182	185	205
Titan	137	232	189	183	149	182
Mean	162	228	200	173	161	185
LSD$_{(\alpha = 0.05)}$ [a]	23	26	18	18	19	20

[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, Stuttgart, Arkansas, during 2019.

	Milling Yield by Seeding Date						
Cultivar	**21 March**	**5 April**	**20 April**	**2May**	**15 May**	**4 June**	**Average**
	(%HR/%TR)[a]						
ARoma 17	67/71	69/73	66/71	65/70	57/69	66/70	65/71
CL153	65/71	67/72	66/72	63/70	61/69	67/71	65/71
CL272	67/71	66/72	67/71	63/69	49/69	66/70	63/70
CLL15	64/70	63/71	64/71	64/69	53/67	64/69	62/69
CLL16	60/69	59/70	58/69	62/68	55/68	60/67	59/69
CLM04	69/71	67/70	66/71	65/69	51/69	66/69	64/70
Diamond	64/72	60/71	61/71	61/69	54/69	62/69	61/70
Jewel	61/71	62/72	60/71	62/70	61/70	63/70	62/71
Jupiter	67/69	66/69	67/69	67/69	62/68	64/67	65/68
Lynx	69/71	66/70	64/69	66/70	50/70	65/69	63/70
PVL01	64/72	63/71	63/71	63/70	60/69	64/70	63/71
RT 3201	67/70	60/70	67/71	68/71	45/69	66/70	63/70
RT 7301	64/71	61/71	64/72	66/72	49/70	66/72	61/71
RT 7321 FP	60/71	60/71	59/71	63/72	45/70	65/71	59/71
RT 7501	64/71	64/72	63/72	65/71	52/70	66/71	62/71
RT 7521 FP	64/71	62/71	61/70	63/70	53/70	65/70	61/70
RT CLXL745	64/71	61/72	60/71	64/72	50/70	65/71	61/71
RT Gemini 214 CL	63/71	62/70	62/71	64/71	55/70	64/70	62/70
RT XP753	63/72	60/72	62/72	65/72	49/71	65/72	61/72
Titan	66/69	61/70	67/70	64/69	45/67	65/69	61/69
Mean	65/71	63/71	63/71	64/70	53/69	65/70	62/70
LSD$_{(\alpha = 0.05)}$ %HR[b]	3	2	2	2.1	5	1	3
LSD$_{(\alpha = 0.05)}$ %TR	2	3	1	1	1	1	1

[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, near Colt, Arkansas, during 2019.

Cultivar	Milling Yield by Seeding Date					Average
	2 April	24 April	8 May	28 May	12 June	
	(%HR/%TR)[a]					
ARoma 17	62/71	66/70	65/71	63/69	64/70	64/70
CL153	61/71	62/68	59/69	59/68	61/68	61/69
CL272	43/67	64/69	57/69	51/67	57/68	56/68
CLL15	55/69	63/67	60/70	55/67	58/67	58/68
CLL16	50/69	58/66	58/69	57/67	57/67	56/68
CLM04	60/69	64/67	64/69	64/69	64/68	63/68
Diamond	48/70	62/68	57/70	60/70	61/69	58/70
Jewel	59/72	62/68	61/70	62/70	61/70	61/70
Jupiter	65/68	62/65	64/67	61/65	62/65	63/66
Lynx	59/70	64/68	63/69	59/68	62/68	62/69
PVL01	57/70	62/68	61/69	60/69	59/69	60/69
RT 3201	53/69	66/69	61/70	50/67	59/68	58/69
RT 7301	48/70	64/71	55/70	54/69	51/69	55/70
RT 7321 FP	49/71	63/71	53/71	47/69	55/69	53/70
RT 7501	58/70	63/69	55/69	59/68	61/69	59/69
RT 7521 FP	58/71	62/69	59/70	61/69	60/69	60/70
RT CLXL745	53/71	64/71	56/71	55/69	59/69	58/70
RT Gemini 214 CL	55/70	62/69	55/70	61/69	60/69	59/69
RT XP753	50/71	65/71	56/71	52/69	56/70	56/70
Titan	56/69	66/68	58/69	54/66	61/67	59/68
Mean	55/70	63/69	58/70	57/68	59/68	59/69
LSD$_{(\alpha = 0.05)}$ % HR[b]	3	2	3	2	3	3
LSD$_{(\alpha = 0.05)}$ % TR	1	1	1	1	1	1

[a] %HR/%TR = percent head rice/percent total rice.

[b] LSD = least significant difference.

Water Management Effects on Trace Gas Emissions Under Greenhouse Conditions from Direct-Seeded Hybrid Rice in a Silt-Loam Soil

D. Della Lunga,[1] K.R. Brye,[1] J.M. Slayden,[1] S.G. Lebeau,[1] T.L. Roberts,[1] and R.J. Norman[1]

Abstract

Water management regimes influence greenhouse gas emissions in rice (*Oryza sativa* L.) production. The objective of this study was to quantify methane (CH_4), nitrous oxide (N_2O), and carbon dioxide (CO_2) under direct-seeded conditions in the greenhouse to evaluate the effects of water regime on fluxes and growing-season-long emissions. Research was conducted during 2019 using a hybrid rice cultivar (RT 7311 CL) grown in a DeWitt silt loam (Albaqualf). Six plastic tubs, filled with soil and manually seeded, were arranged in a completely random design in the greenhouse with two replications of three water regime treatments: i) flooded, ii) saturated, but not flooded, and iii) moist soil (i.e., slightly below saturation). On 13 different dates, gas sampling occurred. Methane, N_2O, and CO_2 fluxes differed among water regimes over time ($P < 0.05$). End-of-season aboveground rice dry matter differed among water regimes ($P < 0.05$). Aboveground dry matter was more than two times greater from the flooded-soil than from the non-flooded treatments. Root dry matter was unaffected by water regime due to large measured variability. Season-long CH_4 and CO_2 emissions differed among water regimes ($P < 0.05$) and were larger from the flooded-soil condition than from the moist-soil and nearly saturated conditions, while season-long N_2O emissions were unaffected by water regime. Characterizing the effects of soil moisture content could improve the understanding of the dynamics that regulate production of greenhouse gases in rice production systems.

Introduction

Different water management and field preparation practices greatly affect the production and emissions of greenhouse gases (GHGs) from rice (*Oryza sativa* L.) fields (Pittelkow et al., 2015). Continuous flooding, intermittent flooding, also known as alternate wetting drying (AWD), and delayed flooding (DF), in combination with cultural practices, like conventional tillage (CT) or no-tillage (NT), have been studied to determine the environmental impact of these varying practices. The drying process associated with AWD and DF causes an increase in soil oxidation-reduction (redox) potential and favors oxidation and microbial reactions, such as the nitrification of ammonium hydrolyzed from synthetic fertilizers (i.e., urea). As a result, methane (CH_4) emissions decrease, while nitrous oxide (N_2O) emissions increase compared to emissions from continuously flooded conditions (Rector et al., 2018). Nitrification-denitrification, methanogenesis-methanotrophy, and soil respiration are the main mechanisms responsible for the production of N_2O, CH_4, and carbon dioxide (CO_2), respectively, in the soil.

The objective of this study was to assess and quantify CH_4, N_2O, and CO_2, released from a silt-loam soil under direct-seeded conditions in the greenhouse and to evaluate the effects of water regime (i.e., near saturation, moist conditions, and flooded) on fluxes and growing-season emissions. It was hypothesized that CH_4 emissions would be greater in flooded than non-flooded treatments due to the development of anaerobic soil conditions, while N_2O emissions will be greater from near-saturated than from moist-soil or flooded conditions due to a more optimal environment for nitrification and denitrification. It was hypothesized that CO_2 emissions would be greater in moist-soil treatments due to more aerobic soil conditions.

Procedures

This study was conducted in the greenhouse between February and May 2019 at the University of Arkansas System Division of Agriculture Milo J. Shult Agricultural Research and Extension Center, Fayetteville, Arkansas. Six, 13.4-gallon (51 L) plastic tubs [20 in. (51 cm) wide by 26.4 in. (67 cm) long by 6 in. (15 cm) deep] were placed on the same greenhouse bench under controlled and constant conditions. Each tub was filled with 47.3 lb (21 kg) of soil collected from the Rice Research and Extension Center (RREC; 34.46°N, -91.46°W) near Stuttgart in Arkansas County, Arkansas. The soil was collected from the top 4 in. (10 cm) of a furrow-irrigated rice field that had been under cultivated agriculture for at least 15 years and was classified as DeWitt silt loam (fine, smectitic, thermic Typical Albaqualfs).

Tubs were manually seeded with the hybrid cultivar RT 7311 CL (RiceTec, Alvin, Texas) on 7 February 2019. From 7 February to 6 March 2019, all tubs were manually watered uniformly every day with tap water until the soil was visually wet, but not saturated. On 7 March 2019, the equivalent of 200 lb/ac (6.3 g) of nitrogen (N) as urea and the equivalent of 120 lb/ac (3.8 g) of potassium (K) as muriate of potash were manually uniformly applied to the soil surface of each tub, in which the soil surface was somewhat dry because no irrigation water had been applied within the previous 24 hours. On 8 and 9 March 2019, each tub

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[1] Graduate Student, Professor of Applied Soil Physics and Pedology, Graduate Student, Graduate Student, Associate Professor of Soil Fertility/Soil Testing, and Professor, respectively, Department of Crop, Soil, and Environmental Sciences, Fayetteville.

was flooded to a depth of 2 in. (5 cm) to allow the fertilizer to dissolve and penetrate into the soil. On 11 March 2019, a 12-in. (30-cm) diameter and 12-in. (30-cm) tall polyvinyl chloride (PVC) base collar was installed in each tub to a depth of 4.7 in. (12 cm).

The six tubs were arranged in a completely random design with two replications of three water regime treatments: i) flooded, ii) saturated, but not flooded, and iii) moist soil (i.e., slightly below saturation). Flooded conditions were established permanently on 10 March 2019 in two of the tubs, while two tubs were kept at a constant volumetric water content of 0.44 cm^3 cm^{-3} (i.e., moist soil), and the last two tubs were kept at a constant volumetric water content of 0.56 cm^3 cm^{-3} (i.e., saturation). The appropriate volume of tap water was measured with a 0.3-gal (1 L) graduated cylinder and transferred to a 2-gallon watering can that was used to irrigate the tubs to reach the desired target volumetric water content (i.e., 0.44 or 0.56 cm^3 cm^{-3}).

On 13 different dates [i.e., 37, 41, 48, 50, 55, 62, 69, 76, 83, 90, 97, 105, and 112 days after planting (DAP)], gas sampling occurred (Rogers et al., 2014; Smartt et al., 2015; Rector et al., 2018). Gas samples were collected at 20-minute intervals (i.e., 0, 20, 40, 60 minutes) over a 1-hour period with a 1.2-$in.^3$ (20 mL) syringe. Gas samples were analyzed with a Shimadzu GC-2014 gas chromatograph (GC; Shimadzu North America/Shimadzu Scientific Instruments Inc., Columbia, Md.). At the end of the experiment (i.e., 114 DAP), aboveground and root biomass were collected from inside the collars, dried for 7 days in a forced-draft oven at 131 °F (55 °C), and weighed.

Based on a completely random experimental design, a two-factor analysis of variance (ANOVA) was performed in SAS V. 9.4 (SAS Institute, Inc., Cary, N.C.) to evaluate the effect of water regime (i.e., moist, near saturated, and flooded), time (i.e., DAP), and their interaction on gas fluxes (i.e., CH_4, N_2O, and CO_2). A separate ANOVA was conducted to evaluate the effect of water regime on season-long emissions and aboveground and root dry matter. Significance was judged at the 0.05 level for all statistical tests.

Results and Discussion

Methane, N_2O, and CO_2 fluxes differed ($P < 0.05$) among water regimes over time. The evaluation of least square means (LSM) determined that 95% (74 out of 78) of individual CH_4 fluxes did not differ from zero. The remaining 5% (4 out of 78) of individual CH_4 fluxes that differed from zero were from the flooded-soil treatment at 97, 105, and 112 DAP, except for one flux from the nearly saturated treatment (i.e., 0.56 cm^3 cm^{-3}) that occurred at 112 DAP (Fig. 1). Similar to CH_4, only 6.4% (5 out of 78) of N_2O fluxes differed from zero and were all measured in the first half of the growing season, specifically at 37, 41, 48, 50, and 55 DAP (Fig. 1). The N_2O fluxes at 37, 41, and 48 DAP occurred from the nearly saturated water regime, while the N_2O fluxes at 50 and 55 DAP occurred from the moist-soil and flooded-soil condition, respectively. In contrast to CH_4 and N_2O, 27% of the CO_2 fluxes differed from zero, where most occurred during the second half of the growing season at 48, 50, 55, 62, 69, 76, 83, 90, 97, 105,and 112 DAP and most occurred from the nearly saturated (i.e., 48, 50, 55, 76, 83, 97, 105, and 112 DAP) and flooded-soil (i.e., 55, 62, 69, 76, 83, 90, 97, 105, and 112 DAP) conditions (Fig. 1).

End-of-the-season above-ground rice dry matter (DM) differed ($P = 0.03$) among water regimes. Aboveground DM was more than two times greater from the flooded-soil (14.6 ton/ac) than from the non-flooded treatments, which did not differ and averaged 7.05 ton/ac. Though root DM ranged from 8.6 ton/ac in the moist-soil to 24.1 ton/ac in the flooded-soil condition, root DM was unaffected by water regime due to large measured variability.

Season-long CH_4 emissions differed among water regimes ($P = 0.05$) and were larger from the flooded-soil condition (9.06 lb CH_4-C/ac/season, 10.16 kg CH_4-C/ha/season) than from the moist-soil (3.14 lb CH_4-C/ac/season, 3.52 kg CH_4-C/ha/season) and nearly saturated (3.64 lb CH_4-C/ac/season, 4.08 kg CH_4-C/ha/season) conditions (Table 1). In contrast to CH_4 emissions, N_2O emissions were unaffected by water regime ($P > 0.05$) and ranged from 1.65 lb N_2O-N/ac/season (1.89 kg N_2O-N/ha/season) from the moist-soil to 5.52 lb N_2O-N/ac/season (6.19 89 kg N_2O-N/ha/season) from the nearly saturated condition and averaged 3.33 lb N_2O-N/ac/season (3.73 kg N_2O-N/ha/season) across all three water regimes (Table 1). Similar to CH_4, CO_2 emissions differed among water regimes ($P = 0.04$) and were larger from the flooded-soil conditions (5688 lb CO_2-C/ac/season, 6365 kg CO_2-C/ha/season) than from moist-soil (1993 lb CO_2-C/ac/season, 3235 kg CO_2-C/ha/season) and nearly saturated (2886 lb CO_2-C/ac/season, 3235 kg CO_2-C/ha/season) conditions, which did not differ (Table 1).

Practical Applications

The results of this study showed the large influence that soil moisture content has on GHG emissions, specifically CH_4, N_2O, and CO_2, for estimating the environmental impacts of rice production systems. The differences in season-long GHG emissions between water regimes were substantial, this will likely affect the estimated global warming potential associated with the various water regimes evaluated. Characterizing the effects of various environmental factors, like soil moisture content, could improve the understanding of the dynamics that regulate GHG production and release in rice production systems.

Acknowledgments

The authors thank Ryan Greenfield for fieldwork and laboratory assistance. The authors also wish to thank the University of Arkansas System Division of Agriculture for support of this study.

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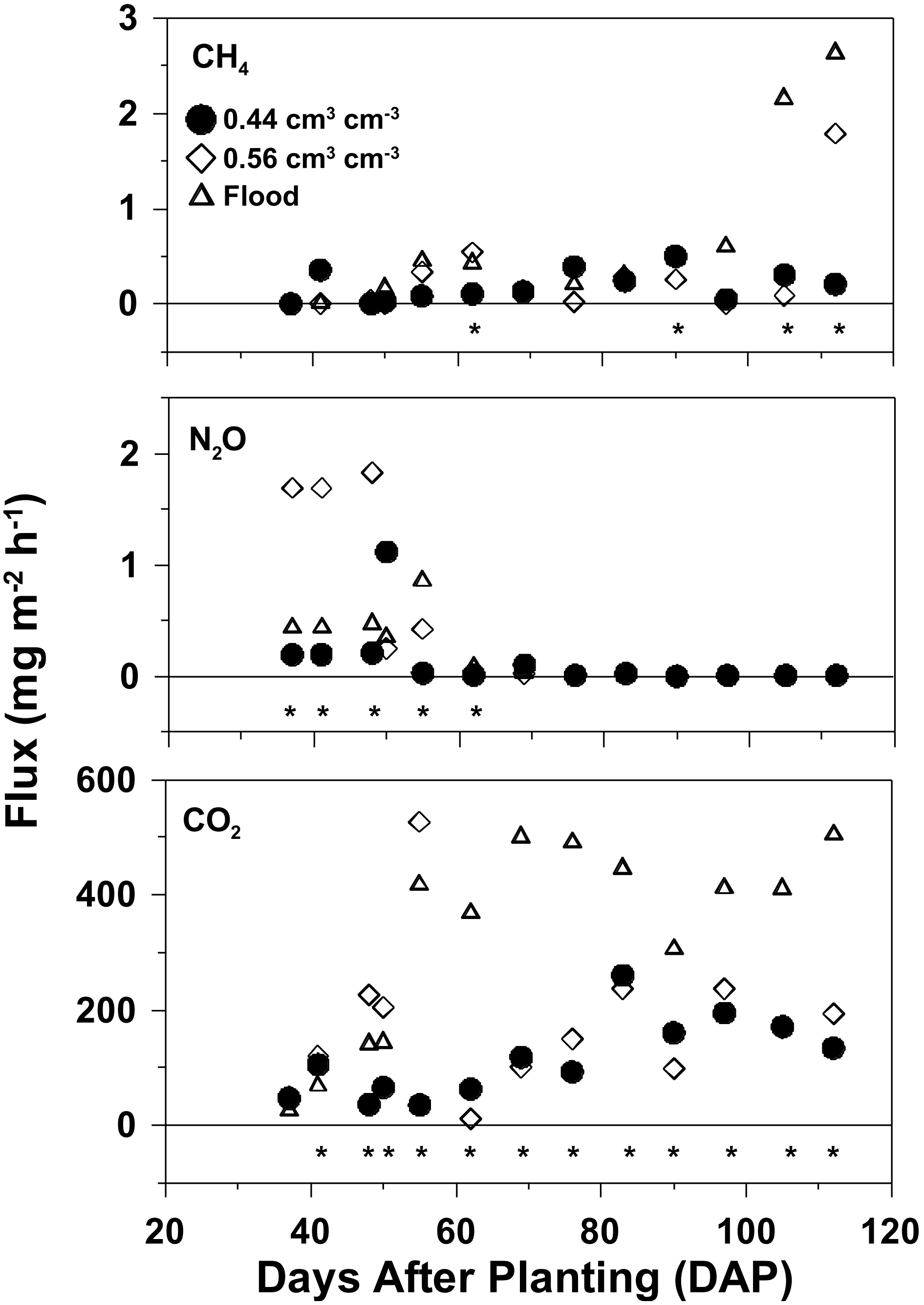

Fig. 1. Methane (CH_4), nitrous oxide (N_2O), and carbon dioxide (CO_2) flux over time [days after planting (DAP)] among water regimes during the 2019 growing season in the greenhouse. Days after planting marked with an asterisk (*) indicated a significant difference in fluxes among the water regimes on that day.

Table 1. Summary of methane, nitrous oxide, and carbon dioxide emissions and emissions intensity (n = 2) among the different water regimes during the 2019 growing season in the greenhouse.

	Water Regime		
Gas/Emissions Property	**0.44 cm^3 cm^{-3}**	**0.56 cm^3 cm^{-3}**	**Flood**
Methane			
Emissions (lb CH_4-C/ac/season)	3.14 b[†]	3.64 b	9.06 a
Intensity (lb CH_4-C/ton aboveground dry matter)	0.47 a	0.49 a	0.62 a
Intensity (lb CH4-C/ton root dry matter)	0.36 a	0.26 a	0.38 a
Nitrous Oxide			
Emissions (lb N_2O-N/ac/season)	1.65 a	5.52 a	2.82 a
Intensity (lb N_2O-N/ton aboveground dry matter)	0.25 a	0.75 a	0.19 a
Intensity (lb N_2O-N/ton root dry matter)	0.19 a	0.40 a	0.12 a
Carbon Dioxide			
Emissions (lb CO_2-C/ac/season)	1993.00 b	2886.00 b	5688.00 a
Intensity (lb CO_2-C/ton aboveground dry matter)	297.00 a	391.00 a	391.00 a
Intensity (lb CO_2-C/ton root dry matter)	231.00 a	207.00 a	236.00 a

[†] Means in same row followed by different letters are different at $P < 0.05$.

Grain Yield Response of Four New Rice Cultivars to Seeding Rate

D.L. Frizzell,[1] J.T. Hardke,[1] E. Castaneda-Gonzalez,[1]
T.D. Frizzell,[1] K.F. Hale,[1] and T.L. Clayton[1]

Abstract

The cultivar × seeding rate studies determine the proper seeding rates for new rice (*Oryza sativa*, L.) cultivars over a range of production/growing conditions in Arkansas. The four rice cultivars evaluated in 2019 were CLL15, CLM04, PVL01, and PVL02. Each cultivar was seeded at 10, 20, 30, 40, and 50 seed/ft^2. In accordance with current recommendations and predominant grower practice, all seed received insecticide and fungicide seed treatments. Trials were seeded at two on-farm locations in eastern Arkansas. Stand density and grain yield results were consistent with current seeding rate recommendations of 30 seed/ft^2 (65 to 80 lb/ac) under optimum conditions and seeding dates on silt loam soils. It should be noted that without the use of insecticide and fungicide seed treatments, stand density and grain yield may be reduced compared to results in this study. At Greene County during 2019, grain yield of each cultivar increased as seeding rate increased. However, reduced grain yield was observed at the lowest (10 seed/ft^2) seeding rate and suboptimal stand density (<10–20 plants/ft^2) was noted at seeding rates of 10–30 seed/ft^2 for CLL15, PVL01, and PVL02 and 10–20 seed/ft^2 for CLM04. Optimal grain yield of 95% or greater and optimal stand density of 10–20 plants/ft^2 was achieved in 3 of the 4 cultivars using seeding rates of 40–50 seed/ft^2 at this location. At Poinsett County, grain yield increased as seeding rate increased for PVL01 but was not significant for CLL15, CLM04, or PVL02. The seeding rates that resulted in greater than 95% optimal grain yield varied between the cultivars, but optimal stand density was noted for CLL15, PVL01, and PVL02 at 20–30 seed/ft^2 and 20–40 seed/ft^2 for CLM04. Seeding rates below or above these resulted in stand density less than or greater than 10–20 plants/ft^2, respectively.

Introduction

Optimal rice (*Oryza sativa*, L.) stand density for pure-line cultivars is considered to be 10 to 20 plants/ft^2 (Hardke et al., 2018). Rice seeding rate is adjusted as needed to meet field specific conditions but generally 30 seed/ft^2 on silt loam soils and 36 seed/ft^2 on clay soils are adequate to obtain the desired stand density. The use of an insecticide seed treatment has been shown to increase stand density by over 10% and increase grain yield by an average of 8 bu./ac (Taillon et al., 2015). The use of an insecticide seed treatment has increased in recent years and is currently used on approximately 74% of the rice acres in Arkansas (Hardke, 2019). Lower stand densities and grain yields may be expected when planting without the use of insecticide seed treatments.

The release of new cultivars, combined with changes in production practices, including the use of insecticide and fungicide seed treatments, requires the continued evaluation of seeding rates for new cultivars to ensure recommendations maximize the profit potential for rice growers. The objective of this study was to determine the optimal seeding rate to maximize grain yield for four new rice cultivars in environments and growing conditions common to Arkansas rice production.

Procedures

The two on-farm locations for the 2019 cultivar × seeding rate studies included a grower field in Greene Co. on a silt loam soil near Delaplaine, Arkansas, and a grower field in Poinsett Co. on a silt loam soil near Jonesboro, Arkansas. The pure-line cultivars CLL15, CLM04, PVL01, and PVL02 were seeded at Greene Co. on 11 April and at Poinsett Co. on 17 May. All seed was treated with NipsIt SUITE® seed treatment containing an insecticide and fungicides and also Zinche® seed treatment containing 32.5% zinc oxide. Seeding rates evaluated for each cultivar were 10, 20, 30, 40, and 50 seed/ft^2. The midpoint of 30 seed/ft^2 corresponds to 65 to 80 lb seed/ac for most cultivars and is the base recommendation on well-prepared silt loam soils. Plots were 8 rows (7.5-in. spacing) wide and 16.5 ft in length. Cultural practices otherwise followed recommended practices for maximum yield. The experimental design for all trials and cultivars was a randomized complete block design with six replications.

Stand density was determined 3–4 weeks after rice emergence by counting the number of seedlings that emerged in 10 row ft. Nitrogen (N) was applied to studies at the 4- to 6-lf growth stage in accordance with the grower's standard practice. At maturity, the center 4 rows of each plot were harvested, and the moisture content and weight of grain were determined. Grain yields were adjusted to 12% moisture and reported on a bushels/acre (bu./ac) basis. 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 ($P = 0.05$).

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[1] Program Associate, Rice Extension Agronomist, Program Associate, Program Technician–Rice Agronomy, Program Associate–Rice Agronomy, and Program Associate, respectively, Department of Crop, Soil, and Environmental Sciences, Stuttgart.

Results and Discussion

During 2019, stand density was influenced by a cultivar × seeding rate interaction at each location. At Greene Co. on a silt loam soil, stand density of each of the 4 cultivars increased numerically as seeding rate increased from 10 to 50 seed/ft^2 and was optimized utilizing seeding rates of 40–50 seed/ft^2 (Table 1). Stand density within the recommended range of 10–20 plants/ft^2 was obtained using 30–50 seed/ft^2 when seeding CLM04 and 40–50 seed/ft^2 when seeding CLL15, PVL01, and PVL02. All seeding rates lower than 30 seed/ft^2 resulted in stand density lower than 10 plants/ft^2.

At Poinsett Co. on a silt loam soil, stand density within each cultivar increased as seeding rate increased from 10 to 50 seed/ft^2 (Table 1). Stand density within the recommended range of 10–20 plants/ft^2 was obtained using 20–30 seed/ft^2 for CLL15, 20–40 seed/ft^2 for CLM04, and 20–30 seed/ft^2 for PVL01 and PVL02. Seeding rates of 10 or 50 seed/ft^2 resulted in stand densities below or above the recommended range, respectively. The seeding rate of 40 seed/ft^2 also resulted in stand density greater than 20 plants/ft^2 during 2019 at this location.

During 2019, grain yield was influenced by a cultivar × seeding rate interaction at both Greene and Poinsett Counties (Table 2). At Greene Co., grain yield of CLL15 and CLM04 increased as seeding rate increased and was optimized at 30–50 seed/ft^2. Seeding rates of 10–20 seed/ft^2 resulted in the lowest grain yield for CLL15, and 10 seed/ft^2 resulted in the lowest grain yield for CLM04. Grain yields of PVL01 and PVL02 generally increased as seeding rate increased from 10 to 50 seed/ft^2 and were optimized at 40–50 seed/ft^2. Lowest grain yields were noted at the 10 seed/ft^2 seeding rate.

The cultivar × seeding rate interaction was significant only for the grain yield of PVL01 at Poinsett Co. during 2019 (Table 2). The grain yield of PVL01 was optimized using 30–50 seed/ft^2 and was lowest when the seeding rate was 10–20 seed/ft^2. Grain yield of CLL15, CLM04, and PVL02 were not influenced by seeding rate at Poinsett Co. during this study year.

A comparison of grain yields of each cultivar at both locations by converting to percent of optimal yield is provided in Fig. 1. At Greene Co., CLL15 grain yield was maximized at the 40 seed/ft^2 seeding rate, and greater than 95% optimal grain yield was obtained with a seeding rate of 40 or 50 seed/ft^2. Cultivar CLM04 grain yield was maximized at 50 seed/ft^2 and greater than 95% optimal grain yield was obtained using 40–50 seed/ft^2. Maximum grain yield for PVL01 at this location was obtained at 50 seed/ft^2, which was also the only seeding rate resulting in 95% optimal grain yield during this study year. Cultivar PVL02 grain yield was maximized at the 40 seed/ft^2 seeding rate, and seeding rates of 40–50 seed/ft^2 resulted in greater than 95% optimal grain yield.

At Poinsett Co. during 2019, grain yield was maximized for CLL15 at 40 seed/ft^2, and greater than 95% optimal grain yield was obtained using 40–50 seed/ft^2 (Fig. 1). Grain yield was maximized for CLM04 at a seeding rate of 10 seed/ft^2; however, greater than 95% optimal grain yield was also noted at seeding rates of 20 and 50 seed/ft^2. Maximized grain yield of PVL01 was obtained using 40 seed/ft^2, and greater than 95% optimal grain yield was obtained using seeding rates of 30–50 seed/ft^2. Grain yield of PVL02 was maximized at 20 seed/ft^2, and greater than 95% optimal grain yield was observed at seeding rates of 40 and 50 seed/ft^2.

At Greene Co. during 2019, the lower seeding rate of 10–30 seed/ft^2 resulted in less than 95% optimal grain yields and stand density lower than the recommended range for the four cultivars. The exception would be stand density of 12.4 plants/ft^2 of CLM04 seeded at 30 seed/ft^2. All varieties at Greene Co. showed markedly lower optimal grain yields when seeded at 10 seed/ft^2. Although this location is a silt loam soil, with a well-prepared seedbed, planted within the recommended planting window for that geographic area, a base seeding rate of more than 30 seed/ft^2 was needed to achieve stand density of 10–20 plants/ft^2 in each of the 4 cultivars due to delayed emergence and reduced overall stand densities.

At Poinsett Co. during 2019, the lowest seeding rate of 10 seed/ft^2 generally resulted in the lowest optimal grain yield and lower than recommended stand density. Seeding rates of 20–30 seed/ft^2 were necessary to obtain a recommended stand density of 10–20 plants/ft^2. These seeding rates also resulted in close to, or greater than, 95% optimal grain yield for each of the 4 cultivars at this location. With the exception of CLM04 seeded at 40 seed/ft^2, seeding rates of 40–50 seed/ft^2 resulted in stand density greater than 20 plants/ft^2.

Practical Applications

The cultivar × seeding rate studies in 2019 agree with previous research that an optimum seeding rate for new rice cultivars grown on a silt loam soil and well-prepared seedbed and within the recommended planting window for a given location is approximately 30 seed/ft^2. Seeding rates lower than the current recommendation risk insufficient stand densities that will be unable to maximize grain yield potential. However, seeding rates greater than the baseline recommendation of 30 seed/ft^2 risk the potential for stand density greater than the recommended 10–20 plants/ft^2, which could contribute to increased disease pressure or lodging. This dataset also suggests the need to address specific seeding rate requirements on an individual field basis.

The findings from this study are based on results from silt loam soils and currently recommended seeding rate adjustments based on soil type and seeding date. Environmental conditions should also 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 funds administered by the Arkansas Rice Research and Promotion Board, the support from the University of Arkansas System Division of Agriculture, and Horizon Ag. Thank you to Dave Freeze, Greene County Cooperative Extension Service, and Craig Allen and Jeffery Works, Poinsett County Cooperative Extension Service, for their help with this study.

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Table 1. Influence of seeding rate on stand density at two locations during 2019.

	Stand Density							
Seeding	Greene[†]				Poinsett			
Rate	CLL15	CLM04	PVL01	PVL02	CLL15	CLM04	PVL01	PVL02
(seed/ft^2)	(plants/ft^2)							
10	4.2 d[‡]	5.1 d	4.3 b	4.6 c	7.3 c	5.5 d	9.5 b	7.4 d
20	7.2 c	9.3 c	6.9 b	6.3 bc	11.6 c	11.1 cd	11.8 b	13.9 c
30	9.6 c	12.4 bc	7.0 b	9.0 b	20.4 b	15.3 bc	20.3 a	18.2 c
40	12.3 b	14.0 ab	10.5 a	14.3 a	24.2 b	20.2 ab	22.3 a	27.5 b
50	15.4 a	17.1 a	12.5 a	15.9 a	33.4 a	24.0 a	25.3 a	34.4 a
LSD$_{0.05}$[§]	2.7	3.8	3.2	3.5	4.5	6.8	7.4	4.7

[†] Greene = farmer field in Greene Co. on a silt loam soil; and Poinsett = farmer field in Poinsett Co. on a silt loam soil.

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

[§] LSD = least significant difference.

Table 2. Influence of seeding rate on grain at two locations during 2019.

	Grain Yield							
Seeding	Greene[†]				Poinsett			
Rate	CLL15	CLM04	PVL01	PVL02	CLL15	CLM04	PVL01	PVL02
(seed/ft^2)	(bu./ac)							
10	155.0 c[‡]	163.8 c	125.7 c	127.9 c	186.7	193.8	158.0 c	159.0
20	172.0 bc	182.4 b	152.8 b	141.4 b	188.8	187.2	163.5 bc	172.6
30	185.3 ab	189.0 ab	152.8 b	143.9 b	191.1	175.5	171.8 ab	162.9
40	197.8 a	197.5 ab	159.7 ab	157.1 a	203.1	172.9	176.0 a	165.5
50	196.4 a	203.6 a	171.6 a	151.6 ab	194.4	186.8	173.9 a	164.5
LSD$_{0.05}$[§]	22.9	17.3	15.0	12.4	NS[¶]	NS	10.3	NS

[†] Greene = farmer field in Greene Co. on a silt loam soil; and Poinsett = farmer field in Poinsett Co. on a silt loam soil.

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

[§] LSD = least significant difference.

[¶] NS = not significant.

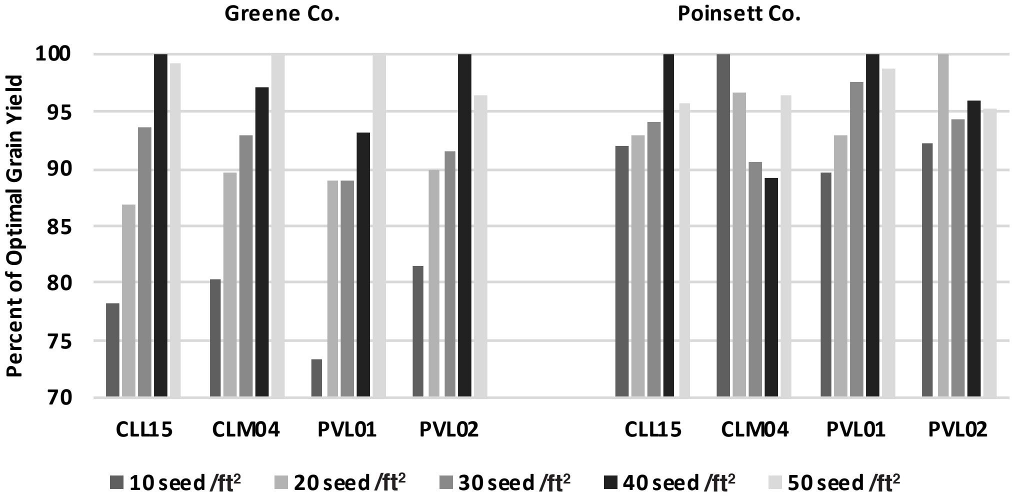

Fig. 1. Influence of seeding rate on rice grain yield in on-farm seeding rate trials in Greene and Poinsett Counties during 2019. Percent of optimal grain yield calculated based on the highest grain yield for each variety at each location equivalent to 100% optimal grain yield.

Grain Yield Response of Diamond to Seeding Rate and Planting Date

D.L. Frizzell,[1] J.T. Hardke,[1] E. Castaneda-Gonzalez,[1] T.D. Frizzell,[1] K.F.Hale,[1] T.L. Clayton,[1] and A. Ablao[2]

Abstract

Traditional seeding rate studies are utilized to determine the proper seeding rates for new rice (*Oryza sativa*, L.) cultivars over a range of production/growing conditions in Arkansas. However, rice in Arkansas is planted from late March through June, exposing the crop to a range of environmental conditions that may impact performance related to seeding rate. During 2019, treatments included Diamond seeded at 10, 20, 30, 40, and 50 seed/ft^2, and all seed received insecticide and fungicide seed treatments in accordance with current recommendations and predominant grower practice. Trials were seeded at 2 University of Arkansas System Division of Agriculture research stations in 2019: 2 April, 24 April, 8 May, 28 May, and 12 June at the Pine Tree Research Station, near Colt, Arkansas and 21 March, 3 April, 16 April, 29 April, 17 May, and 4 June at the Rice Research and Extension Center in Stuttgart, Arkansas. Stand density and grain yield results were consistent with current seeding rate recommendations where 30 seed/ft^2 (65 to 80 lb/ac) is consistently required to achieve optimal yield, and higher seeding rates may be needed when planting early (March) or late (June). It should be noted that without the use of insecticide and fungicide seed treatments, stand density and grain yield may be reduced compared to results in this study. Grain yield response to seeding rate was evident at both locations in 2019. Reduced grain yield was observed at the lowest (10 seed/ft^2) seeding rate.

Introduction

Optimal rice (*Oryza sativa*, L.) stand density for pure-line cultivars is considered to be 10 to 20 plants/ft^2 (Hardke et al., 2019). The base recommended seeding rate for rice in Arkansas is 30 seed/ft^2 for pure-line varieties on silt loam soils. The seeding rate is then adjusted upward based on the seeding method, soil type, seedbed preparation, and seeding date. These factors are additive up to a maximum of 50% over the base silt loam seeding rate. Insecticide seed treatment is currently used on approximately 74% of the rice acres in Arkansas (Hardke, 2019). The use of an insecticide seed treatment has been shown to increase stand density by over 10% and increase grain yield by an average of 8 bu./ac (Taillon et al., 2015).

Planting dates outside of the optimum timing have recommendations for increased seeding rates of 10% if planted earlier than the optimum window and 30% if planted later than the optimum window. Recent research is lacking concerning these recommendations for recently released cultivars using seed treatment packages. In addition, the increased use of insecticide and fungicide seed treatments requires that these recommendations be revisited to ensure recommendations maximize the profit potential for rice growers. The objective of this study was to determine the optimal seeding rate at various planting dates to maximize grain yield for Diamond rice in environments and growing conditions common to Arkansas rice production.

Procedures

The two locations for 2019 included the University of Arkansas System Division of Agriculture's Pine Tree Research Station (PTRS), near Colt, Arkansas, and the Rice Research and Extension Center (RREC), Stuttgart, Arkansas. The pure-line cultivar Diamond was seeded at the PTRS on 2 April, 24 April, 8 May, 28 May, and 12 June; and at the RREC on 21 March, 3 April, 16 April, 29 April, 17 May, and 4 June. Weather conditions prevented seeding of a late March test at PTRS during this study year. All seed was treated with NipsIt SUITE® seed treatment containing an insecticide and fungicides and also Zinche® seed treatment containing 32.5% zinc oxide. Seeding rates evaluated were 10, 20, 30, 40, and 50 seed/ft^2. The midpoint of 30 seed/ft^2 corresponds to 65–80 lb seed/ac for most cultivars and is the base recommendation on well-prepared silt loam soils. Plots were 8 rows (7.5-in. spacing) wide and 16.5 ft in length. Cultural practices otherwise followed recommended practices for maximum yield. The experimental design for all trials and seeding dates was a randomized complete block with four replications.

Stand density was determined 3–4 weeks after rice emergence by counting the number of seedlings that emerged in 10 row-ft. A single preflood nitrogen (N) application of 130 lb N/ac was applied to individual studies at the 4- to 6-lf growth stage. At maturity, the center 4 rows of each plot were harvested, and the moisture content and weight of grain were determined. Grain

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[1] Program Associate, Rice Extension Agronomist, Program Associate, Program Technician–Rice Agronomy, Program Associate–Rice Agronomy, and Program Associate, respectively, Department of Crop, Soil, and Environmental Sciences, Stuttgart.

[2] Program Technician, Pine Tree Research Station, Colt.

yields were adjusted to 12% moisture and reported on a bushels/acre (bu./ac) basis. A bushel of rice weighs 45 lb. Data were analyzed using analysis of variance, PROC GLIMMIX, SAS v. 9.4 (SAS Institute, Inc., Cary, N.C.) with means separated using Fisher's least significant difference test ($P = 0.1$).

Results and Discussion

During 2019, there was not a significant planting date × seeding rate interaction at the PTRS or the RREC; therefore, only the main effect of seeding rate on stand density and grain yield will be discussed.

At the PTRS during 2019, stand density increased as the seeding rate increased incrementally from 10 to 50 seed/ft^2 (Table 1). Recommended stand density of 10–20 plants/ft^2 was noted using seeding rates of 20–30 seed/ft^2. Seeding rates of 10, 40, or 50 seed/ft^2 resulted in stand density less than or greater than desired. Grain yield increased as the seeding rate increased from 10 to 30 seed/ft^2 and was similar as the seeding rate increased from 30 to 50 seed/ft^2. Lower than optimum grain yield was noted for seeding rates of 10–20 seed/ft^2 and was optimized during 2019 at this location using seeding rates of 30–50 seed/ft^2.

At the RREC during 2019, stand density increased with each increase in seeding rate from 10 to 50 seed/ft^2 (Table 2). However, the recommended stand density of 10–20 plants/ft^2 was obtained when seeded at 20–30 seed/ft^2. Seeding rates below or above this range resulted in stands less than or greater than the recommended stand density, respectively. Grain yield at this location ranged from 214.5 bu./ac seeded at 10 seed/ft^2 to 231.0 bu./ac seeded at 20 seed/ft^2. Lower than optimum grain yield was noted only for the seeding rate of 10 seed/ft^2 and was optimized using seeding rates of 20–50 seed/ft^2 during 2019.

Practical Applications

Both the PTRS and the RREC are silt loam soil locations within the central geographic region of Arkansas and have similar recommended planting windows and seeding rates. Stand density was lower than the recommended 10–20 plants/ft^2 when seeded at 10 seed/ft^2 and optimized seeded at 20–30 seed/ft^2 at both locations during this study year. Grain yield was optimized when seeded at 30–50 seed/ft^2 at PTRS and when seeded at 20–50 seed/ft^2 at RREC during 2019. The lowest seeding rate of 10 seed/ft^2 resulted in lower than optimum grain yield at both locations this study year.

Seeding rates lower than the current recommendation risk insufficient stand densities that will be unable to maximize grain yield potential. However, seeding rates greater than the recommended silt loam baseline rate of 30 seed/ft^2 risk the potential for stand density greater than the recommended 10–20 plants/ft^2, as was seen at RREC and PTRS during 2019. When no other additive environmental factors are present, increased stand density could contribute to increased disease pressure or lodging. Each of these could result in lower returns for rice growers. It is recommended that environmental conditions 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 funds administered by the Arkansas Rice Research and Promotion Board and the University of Arkansas System Division of Agriculture.

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Table 1. Influence of seeding rate on stand density and grain yield of Diamond at the University of Arkansas System Division of Agriculture's Pine Tree Research Station, near Colt, Arkansas in 2019.

Seeding Rate (seed/ft^2)	Stand Density (plants/ft^2)	Grain Yield (bu./ac)
10	6.2 e†	135.1 c
20	11.7 d	148.7 b
30	16.5 c	160.5 a
40	20.8 b	167.4 a
50	23.7 a	166.1 a
P-value	<0.0001	<0.0001

† Means within a column followed by the same letter are not significantly different ($P < 0.1$).

Table 2. Influence of seeding rate on stand density and grain yield of Diamond at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center, Stuttgart, Arkansas in 2019.

Seeding Rate (seed/ft^2)	Stand Density (plants/ft^2)	Grain Yield (bu./ac)
10	5.8 e†	214.5 b
20	10.9 d	231.0 a
30	16.2 c	228.8 a
40	21.0 b	226.6 a
50	25.3 a	226.2 a
P-value	<0.0001	0.0001

† Means within a column followed by the same letter are not significantly different ($P < 0.1$).

Utilization of On-Farm Testing to Evaluate Rice Cultivars–2019

T.D. Frizzell,[1] J.T. Hardke,[1] D.L. Frizzell,[1] K.F. Hale,[1] E. Castaneda-Gonzalez,[1] W.J. Plummer,[1] T.L. Clayton,[1] and Y. Wamishe[2]

Abstract

On-farm cultivar testing provides the ability to evaluate performance in commercial fields with more unpredictable environments than those at traditional research stations. The Producer Rice Evaluation Program (PREP) utilizes commercial fields throughout the state of Arkansas to evaluate 25 different rice cultivars, including experimental and commercial lines. These on-farm tests are used to analyze different agronomic aspects of cultivars such as disease, lodging, plant stand, plant height, grain yield, and milling yield in diverse environmental conditions, soil types, and growing practices. The most important decision for a producer can be the cultivar that will provide the maximum yield potential for each field. On-farm testing can indicate the cultivars that are best suited for a particular growing situation. Studies were located in grower fields in Craighead, Greene, Lee, Lonoke, Poinsett, Prairie, and Woodruff counties for the 2019 season. The average grain yield across all six locations was 199 bu./ac, and the location with the highest average grain yield average was Woodruff County at 223 bu./ac. The cultivars with the highest average grain yield across all locations were RT XP753, RT Gemini 214 CL, RT 7301, RT 7521 FP, CLL16, RT 7501, Jupiter, RT 7321 FP, Titan, and Diamond. Cultivars with the highest head rice yields were PVL02, CLM04, Jupiter, CLJ01, CL151, CL153, Jazzman-2, ARoma 17, Jewel, Lynx, and PVL01.

Introduction

One goal of the University of Arkansas System Division of Agriculture is to offer a complete production package to producers when southern U.S. rice cultivars are released, including grain and milling yield potential, disease reactions, fertilizer recommendations, and Degree-Day 50 (DD50) Program thresholds. Factors that can influence grain yield potential include: seeding date, soil fertility, water quality and management, disease pressure, weather events, and cultural management practices.

Rice disease can be a major factor in the profitability of any rice field in Arkansas. Host-plant resistance, optimum farming practices, and fungicide (when necessary based on integrated pest management practices) are the best line of defense we have against these profit robbing diseases. The use of resistant cultivars, combined with optimum cultural practices, provide growers with the opportunity to maximize profit at the lowest disease control expense by avoiding the use of costly fungicide applications.

New rice cultivars are developed and evaluated each year at the University of Arkansas System Division of Agriculture under controlled experiment station conditions. A large set of data on grain yield, grain quality, plant growth habit, and major disease resistance is collected during this process. Unfortunately, the dataset under these conditions is not complete for many of the environments where rice is grown in Arkansas because potential problems may not be evident in nurseries grown on experiment stations. With the information obtained from field research coupled with the knowledge of a particular field history, growers can select the cultivar that offers the highest yield potential for their particular situation. The Producer Rice Evaluation Program (PREP) was designed to better address the many risks faced by newly released cultivars across the rice-growing regions of Arkansas. The on-farm evaluation of new and commercial cultivars provides better information on disease development, lodging, grain yield potential, and milling yield under different environmental conditions and crop management practices. These studies also provide a hands-on educational opportunity for county agents, consultants, and producers.

The objectives of the PREP include: 1) to compare the yield potential of commercially available cultivars and advanced experimental lines under commercial production fields; 2) to monitor disease pressure in the different regions of Arkansas; and 3) to evaluate the performance of rice cultivars under those conditions not commonly observed on experiment stations.

Procedures

Field studies were located in Craighead, Greene, Lee, Lonoke, Poinsett, Prairie, and Woodruff counties for the 2019 growing season. Twenty-five cultivars were selected for evaluation in the on-farm tests. Non-Clearfield entries evaluated during 2019 included ARoma 17, Diamond, Jewel, Jupiter, Lynx, Titan, RT 3201, RT XP753, RT 7301, RT 7501, and Jazzman-2. Clearfield or FullPage lines included CLM04, CL272, CL151, CL153, CLL15, CLL16, CLX5-4197, CLJ01, RT CLXL745, RT Gemini 214 CL, RT 7321 FP, and RT 7521 FP. Two Provisia lines included PVL01 and PVL02.

Plots were 8 rows (7.5-in. spacing) wide and 16.5-ft in length arranged in a randomized complete block design with four replications. Pure-line cultivars (varieties) were seeded at a rate of approximately 35.1 seeds/ft^2 (loam and clay soils), and hybrid cultivars were planted at 12.1 seeds/ft^2 (loam and clay soils). Tri-

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[1] Program Technician, Rice Extension Agronomist, Program Associate, Program Associate, Program Associate, Program Technician, and Program Associate, respectively, Department of Crop, Soil, and Environmental Sciences, Stuttgart.

[2] Extension Rice Pathologist, Department of Plant Pathology, Stuttgart.

als were seeded on 28 March (Lee), 11 April (Greene), 30 April (Craighead), 15 May (Woodruff), 17 May (Poinsett), 28 May (Prairie), and 4 June (Lonoke). Since these experiments contain Clearfield, conventional, FullPage, and Provisia entries, all trials were managed as conventional cultivars.

Trials were managed by the grower with the rest of the field in regard to fertilization, irrigation, and weed and insect control, but in most cases did not receive a fungicide application. If a fungicide was applied, it was considered in the disease ratings. Trials were inspected periodically and rated for disease. Percent lodging notes were taken immediately prior to harvest. At maturity, the center four rows of each plot were harvested, the moisture content and weight of the grain were determined, and a subsample of harvested grain was removed for milling purposes. Grain yields were adjusted to 12% moisture and reported on a bushels-per-acre (bu./ac) basis. A bushel weighs 45 lb. The dried rice was milled 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 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 cultivars were represented at all locations during the 2019 growing season. A summary of the results by county and date of seeding is presented in Table 1. Across counties, the grain yield averaged 199 bu./ac. Cultivars RT XP753 and RT Gemini 214 CL were the highest-yielding followed by RT 7301, RT 7521 FP, CLL16, RT 7501, and Jupiter. Cultivars with the highest milling yields included PVL02, CLJ01, CLM04, and Jupiter.

In the Lee Co. trial, the grain yield averaged 219 bu./ac across all cultivars (Table 2). The highest yielding entries were RT Gemini 214 CL, RT 7301, CLL16, Lynx, and CLL15. The entries with the highest milling yields included CLJ01, Jazzman-2, PVL02, CL153, and CLM04. Lee Co. was tied with the lowest milling averages of the 6 trial locations.

In the Greene Co. trial, the grain yield for the cultivars averaged 178 bu./ac (Table 3). Greene Co. was the lowest yielding trial in 2019. The highest yielding cultivars were RT Gemini 214 CL, Jupiter, RT 7521 FP, RT 7501, and CLL16. Percent head rice averaged 62% at Lee Co. during 2019. The highest yielding entries for %HR were Jazzman-2, PVL02, CLJ01, CLM04, and Jupiter.

In the Poinsett Co. trial, RT 7301, RT XP753, RT 7521 FP, RT Gemini 214 CL, and RT 7321 FP were the highest yielding cultivars (Table 4). Notable lodging occurred for Lynx and CLM04. The highest entries for %HR were PVL02, CLM04, and Jewel.

The Lonoke Co. trial average gain yield for the cultivars was 184 bu./ac (Table 5). Cultivars with the highest grain yield included RT 7501, RT Gemini 214 CL, RT XP753, RT 7301, and CLL16. The entries with the highest milling yields included ARoma 17, CLJ01, CL151, CL153, and CLL15. The Lonoke Co. trail had the highest milling yields for the 6 trial locations.

In the Prairie Co. trial, RT XP753, RT Gemini 214 CL, RT 7301, RT 7321 FP, and CLL16 were the highest yielding cultivars, and the average yield for the location was 184 bu./ac (Table 6). Cultivars with the highest %HR included PVL02, CLJ01, Jupiter, and RT 7301.

The Woodruff Co. trial had the highest yielding grain average of all 6 locations at 223 bu./ac (Table 7). The highest yielding cultivars in Woodruff Co. were RT XP753, RT Gemini 214 CL, RT 7301, Diamond, and RT 7521 FP. Notable lodging occurred for Jupiter, Titan, Lynx, and CLM04. Despite having the highest grain yields, Woodruff Co. was tied for the lowest milling yields. The cultivars with the highest milling yields were Lynx, CLM04, PVL01, and Jupiter.

Monitoring cultivar response to disease presence and the severity of reactions is a significant part of this program. The observations obtained from these plots are often the basis for disease ratings developed for use by growers. This is particularly true for a minor disease that may not be encountered frequently, such as narrow brown leaf spot, false smut, and kernel smut.

Yield variability among the study sites represents differences in environments and management practices, but also susceptibility to lodging and disease pressure present at individual locations.

Practical Applications

The 2019 Producer Rice Evaluation Program provided additional data to the rice breeding and disease resistance programs. The program also provided supplemental performance and disease reaction data on new cultivars that will be more widely grown in Arkansas during 2020.

Acknowledgments

The authors appreciate the cooperation of all participating rice producers and thank all Arkansas rice growers for financial support through the Rice Check-Off funds administered by the Arkansas Rice Research and Promotion Board. The authors thank the University of Arkansas System Division of Agriculture for support. The authors especially thank the following county agriculture agents who made this work possible: Keith Perkins, Dave Freeze, Brett Gordon, Branon Thiesse, Jeffrey Works, Craig Allen, Brent Griffin, and Stan Baker.

Table 1. Results of the Producer Rice Evaluation Program (PREP) at 6 locations during 2019.

					Grain yield by location & planting date		
Cultivar	Grain Type[a]	Lodging	Moisture	Milling yield	Lee 3/28	Greene 4/11	Poinsett 5/28
		%	%	%HR/%TR[b]		bu./ac	
Diamond	L	0.0	17.1	63/72	209	178	221
Jewel	L	0.0	16.3	65/72	216	177	211
Jupiter	M	3.9	19.1	67/70	250	207	222
Titan	M	3.2	17.7	63/71	219	184	230
Lynx	M	14.1	17.1	65/72	244	189	172
RT 3201	M	0.0	14.8	62/71	192	160	183
CLM04	M	14.9	17.6	67/71	208	188	170
CL272	M	0.0	16.2	61/71	232	163	185
CL151	L	1.9	16.5	66/72	231	180	195
CL153	L	0.0	16.0	66/72	211	160	186
CLL15	L	0.0	16.1	64/71	238	192	205
CLL16	L	0.0	17.6	62/71	246	197	224
CLX5-4197	L	0.0	16.8	65/72	214	170	203
PVL01	L	0.0	16.8	65/72	196	154	182
PVL02	L	0.0	16.0	68/73	192	152	164
RT CLXL745	L	0.0	14.5	61/72	210	197	207
RT Gemini 214 CL	L	0.0	15.2	62/72	250	211	233
RT 7321 FP	L	0.0	14.4	56/72	217	195	233
RT 7521 FP	L	0.0	15.1	62/72	238	202	235
RT XP753	L	0.0	14.9	60/73	231	190	257
RT 7301	L	0.0	15.0	58/72	246	186	257
RT 7501	L	0.0	16.0	61/71	219	200	221
Jazzman-2	LA	0.0	1.9	66/72	191	115	163
ARoma 17	LA	0.0	16.6	66/72	190	161	185
CLJ01	LA	0.0	16.2	67/72	185	135	175
Mean	-	1.5	15.6	64/72	219	178	205
LSD$_{0.05}$[c]	-	5.2	0.6	2.0/0.4	23.5	21.5	18.0

Continued

Table 1. Continued.

Cultivar	Lonoke 6/04	Prairie 5/28	Woodruff 5/15	Mean[d]
	Grain yield by location and planting date			
	---bu./ac---			
Diamond	198	181	262	208
Jewel	193	186	228	202
Jupiter	190	206	217	215
Titan	184	196	253	211
Lynx	196	191	198	198
RT 3201	191	173	193	182
CLM04	184	176	197	187
CL272	180	163	221	191
CL151	182	153	219	193
CL153	171	168	205	184
CLL15	189	173	201	200
CLL16	203	212	245	221
CLX5-4197	166	175	211	190
PVL01	150	145	196	171
PVL02	154	146	179	164
RT CLXL745	170	196	229	201
RT Gemini 214 CL	216	219	264	232
RT 7321 FP	173	214	252	214
RT 7521 FP	201	209	254	223
RT XP753	210	240	275	234
RT 7301	207	217	263	229
RT 7501	223	198	253	219
Jazzman-2	142	144	197	159
ARoma 17	163	163	193	176
CLJ01	153	154	161	161
Mean	184	184	223	199
$LSD_{0.05}$[c]	17.2	14.7	44.1	22.8

[a] Grain type: L = long-grain; LA = long-grain aromatic; M = medium-grain.

[b] %HR/%TR = % head rice/% total rice.

[c] Least significant difference.

[d] Mean grain yield by cultivar.

Table 2. Results of Lee Co. Producer Rice Evaluation Program (PREP) Trial during 2019. Planted 28 March. Harvested 3 September.

Cultivar	Grain Type[a]	Lodging	Moisture	Grain Yield	Milling Yield
		(%)	(%)	(bu./ac)	(%HR/%TR)[b]
Diamond	L	0	15.0	209	58/71
Jewel	L	0	15.6	216	61/71
Jupiter	M	0	17.6	250	66/70
Titan	M	0	15.9	219	60/69
Lynx	M	0	14.8	244	62/71
RT 3201	M	0	11.9	192	54/70
CLM04	M	0	15.4	208	66/71
CL272	M	0	14.5	232	62/71
CL151	L	0	15.1	231	66/72
CL153	L	0	13.5	211	64/71
CLL15	L	0	14.7	238	64/71
CLL16	L	0	15.8	246	57/69
CLX5-4197	L	0	14.6	214	63/71
PVL01	L	0	14.5	196	64/72
PVL02	L	0	13.5	192	67/72
RT CLXL745	L	0	11.9	210	57/71
RT Gemini 214 CL	L	0	12.9	250	60/71
RT 7321 FP	L	0	12.3	217	52/71
RT 7521 FP	L	0	12.4	238	60/71
RT XP753	L	0	12.1	231	56/71
RT 7301	L	0	12.9	246	56/71
RT 7501	L	0	12.8	219	58/70
Jazzman-2	LA	0	15.4	191	67/72
ARoma 17	LA	0	14.5	190	65/71
CLJ01	LA	0	13.6	185	68/72
Mean	-	0	14.13	219	61/71
$LSD_{0.05}$[c]	-	0	1.4	23.5	2.9/1.0

[a] Grain type: L = long-grain; LA = long-grain aromatic; M = medium-grain.

[b] %HR/%TR = % head rice/% total rice.

[c] Least significant difference.

Table 3. Results of Greene Co. Producer Rice Evaluation Program (PREP) Trial during 2019. Planted 11 April. Harvested 11 September.

Cultivar	Grain Type[a]	Lodging	Moisture	Grain Yield	Milling Yield
		(%)	(%)	(bu./ac)	(%HR/%TR)[b]
Diamond	L	0	15.8	178	60/72
Jewel	L	0	14.6	177	65/73
Jupiter	M	0	18.2	207	67/70
Titan	M	0	14.7	184	62/71
Lynx	M	0	15.4	189	63/71
RT 3201	M	0	13.5	160	61/71
CLM04	M	0	16.0	188	67/71
CL272	M	0	14.2	163	58/71
CL151	L	0	15.2	180	66/73
CL153	L	0	15.0	160	65/72
CLL15	L	0	15.3	192	64/71
CLL16	L	0	17.0	197	61/71
CLX5-4197	L	0	15.3	170	65/72
PVL01	L	0	15.2	154	64/71
PVL02	L	0	14.8	152	68/73
RT CLXL745	L	0	12.8	197	59/72
RT Gemini 214 CL	L	0	13.6	211	56/71
RT 7321 FP	L	0	12.8	195	55/71
RT 7521 FP	L	0	13.3	202	58/70
RT XP753	L	0	14.3	190	58/72
RT 7301	L	0	14.0	186	51/72
RT 7501	L	0	15.8	200	60/71
Jazzman-2	LA	0	15.7	115	69/73
ARoma 17	LA	0	14.9	161	66/72
CLJ01	LA	0	15.0	135	68/72
Mean	-	0	14.9	178	62/72
$LSD_{0.05}$[c]	-	0	1.7	21.5	3.1/0.6

[a] Grain type: L = long-grain; LA = long-grain aromatic; M = medium-grain.

[b] %HR/%TR = % head rice/% total rice.

[c] Least significant difference.

Table 4. Results of Poinsett Co. Producer Rice Evaluation Program (PREP) Trial during 2019. Planted 17 May. Harvested 1 October.

Cultivar	Grain Type[a]	Lodging	Moisture	Grain Yield	Milling Yield
		(%)	(%)	(bu./ac)	(%HR/%TR)[b]
Diamond	L	0	16.1	221	66/73
Jewel	L	0	16.7	211	69/73
Jupiter	M	0	17.9	222	67/71
Titan	M	0	17.0	230	64/71
Ly nx	M	37.5	17.0	172	68/73
RT 3201	M	0	14.0	183	65/71
CLM04	M	37.5	18.0	170	69/73
CL272	M	0	15.1	185	65/72
CL151	L	0	15.2	195	66/72
CL153	L	0	15.1	186	68/73
CLL15	L	0	15.9	205	66/71
CLL16	L	0	16.2	224	64/72
CLX5-4197	L	0	15.8	203	66/72
PVL01	L	0	15.6	182	65/72
PVL02	L	0	15.5	164	69/74
RT CLXL745	L	0	14.4	207	66/73
RT Gemini 214 CL	L	0	15.8	233	66/73
RT 7321 FP	L	0	13.9	233	60/72
RT 7521 FP	L	0	15.0	235	66/73
RT XP753	L	0	13.7	257	64/74
RT 7301	L	0	14.1	257	64/73
RT 7501	L	0	15.0	221	62/71
Jazzman-2	LA	0	15.8	163	68/73
ARoma 17	LA	0	15.4	185	68/73
CLJ01	LA	0	15.0	175	68/72
Mean	-	3.0	15.6	205	66/72
$LSD_{0.05}$[c]	-	15.4	1.5	18.0	2.1/0.7

[a] Grain type: L = long-grain; LA = long-grain aromatic; M = medium-grain.

[b] %HR/%TR = % head rice/% total rice.

[c] Least significant difference.

Table 5. Results of Lonoke Co. Producer Rice Evaluation Program (PREP) Trial during 2019. Planted 4 June. Harvested 17 October.

Cultivar	Grain Type[a]	Lodging	Moisture	Grain Yield	Milling Yield
		(%)	(%)	(bu./ac)	(%HR/%TR)[b]
Diamond	L	0	20.1	198	66/73
Jewel	L	0	17.2	193	67/73
Jupiter	M	0	21.2	190	66/71
Titan	M	0	19.2	184	66/72
Lynx	M	0	19.5	196	68/73
RT 3201	M	0	16.3	191	66/73
CLM04	M	0	18.9	184	67/73
CL272	M	0	19.4	180	62/73
CL151	L	0	18.4	182	69/73
CL153	L	0	18.6	171	68/74
CLL15	L	0	18.3	189	68/73
CLL16	L	0	19.7	203	64/72
CLX5-4197	L	0	18.5	166	67/72
PVL01	L	0	19.3	150	67/73
PVL02	L	0	17.7	154	68/74
RT CLXL745	L	0	16.6	170	63/74
RT Gemini 214 CL	L	0	16.7	216	65/73
RT 7321 FP	L	0	16.4	173	57/73
RT 7521 FP	L	0	17.0	201	66/73
RT XP753	L	0	17.8	210	64/73
RT 7301	L	0	16.9	207	60/73
RT 7501	L	0	17.2	223	66/73
Jazzman-2	LA	0	20.4	142	67/73
ARoma 17	LA	0	20.0	163	71/74
CLJ01	LA	0	18.5	153	70/73
Mean	-	0	18.4	184	66/73
$LSD_{0.05}$[c]	-	0	1.2	17.3	3.9/1.0

[a] Grain type: L = long-grain; LA = long-grain aromatic; M = medium-grain.

[b] %HR/%TR = % head rice/% total rice.

[c] Least significant difference.

Table 6. Results of Prairie Co. Producer Rice Evaluation Program (PREP) Trial during 2019. Planted 28 May. Harvested 8 October.

Cultivar	Grain Type[a]	Lodging	Moisture	Grain Yield	Milling Yield
		(%)	(%)	(bu./ac)	(%HR/%TR)[b]
Diamond	L	0	19.2	181	63/71
Jewel	L	0	18.3	186	65/72
Jupiter	M	0	20.8	206	67/70
Titan	M	0	19.6	196	65/70
Lynx	M	0	18.5	191	66/71
RT 3201	M	0	17.9	173	66/71
CLM04	M	0	19.2	176	65/70
CL272	M	0	18.0	163	62/69
CL151	L	10.0	18.9	153	66/71
CL153	L	0	17.3	168	66/72
CLL15	L	0	17.5	173	63/70
CLL16	L	0	19.9	212	62/70
CLX5-4197	L	0	18.9	175	65/71
PVL01	L	0	18.2	145	65/72
PVL02	L	0	17.3	146	70/74
RT CLXL745	L	0	16.7	196	65/72
RT Gemini 214 CL	L	0	17.1	219	65/71
RT 7321 FP	L	0	16.6	214	62/72
RT 7521 FP	L	0	17.5	209	65/71
RT XP753	L	0	16.1	240	65/73
RT 7301	L	0	16.6	217	66/73
RT 7501	L	0	18.1	198	65/71
Jazzman-2	LA	0	18.4	144	-
ARoma 17	LA	0	19.1	163	66/71
CLJ01	LA	0	18.6	154	68/72
Mean	-	0.4	18.2	184	65/71
$LSD_{0.05}$[c]	-	5.6	1.1	14.7	2.0/0.9

[a] Grain type: L = long-grain; LA = long-grain aromatic; M = medium-grain.

[b] %HR/%TR = % head rice/% total rice.

[c] Least significant difference.

Table 7. Results of Woodruff Co. Producer Rice Evaluation Program (PREP) Trial during 2019. Planted 15 May. Harvested 27 September.

Cultivar	Grain Type[a]	Lodging	Moisture	Grain Yield	Milling Yield
		(%)	(%)	(bu./ac)	(%HR/%TR)[b]
Diamond	L	0	16.5	262	65/73
Jewel	L	0	16.0	228	64/72
Jupiter	M	22.5	19.3	217	66/70
Titan	M	17.5	19.3	253	62/70
Lynx	M	43.75	18.2	198	67/72
RT 3201	M	0	15.8	193	58/70
CLM04	M	47.5	18.8	197	67/71
CL272	M	0	16.8	221	60/71
CL151	L	0	16.9	219	63/71
CL153	L	0	16.5	205	63/72
CLL15	L	0	15.7	201	60/71
CLL16	L	0	18.1	245	64/72
CLX5-4197	L	0	18.2	211	63/71
PVL01	L	0	17.9	196	66/71
PVL02	L	0	17.7	179	65/72
RT CLXL745	L	0	14.8	229	56/72
RT Gemini 214 CL	L	0	15.4	264	59/72
RT 7321 FP	L	0	14.7	252	48/71
RT 7521 FP	L	0	14.9	254	55/71
RT XP753	L	0	15.2	275	54/72
RT 7301	L	0	15.4	263	52/72
RT 7501	L	0	17.4	253	59/70
Jazzman-2	LA	0	16.0	197	61/71
ARoma 17	LA	0	17.0	193	60/71
CLJ01	LA	0	16.8	161	60/71
Mean	-	5.3	16.8	223	61/71
$LSD_{0.05}$[c]	-	23.6	1.8	44.1	9.4/0.9

[a] Grain type: L = long-grain; LA = long-grain aromatic; M = medium-grain.

[b] %HR/%TR = % head rice/% total rice.

[c] Least significant difference.

Yield Responses of Pure-Line and Hybrid Rice to Potassium Fertilization for Long- and Short-Term Trials

C.E. Gruener,[1] N.A. Slaton,[1] T.L. Roberts,[1] J.T. Hardke,[2] and A.D. Smartt[1]

Abstract

Rice (*Oryza sativa* L.) grain yields can be significantly reduced from potassium (K) deficiency on soils low in exchangeable K. Our primary research objective was to explore hybrid and pure-line rice cultivar yield response to K fertilization in six short-term trials and two long-term trials. Selected soil chemical information was collected from each of the trials prior to planting, and harvest data were collected at the end of the season. Soil-test K in the no fertilizer K plots was considered low or very low with Mehlich-3 soil-test K ranging from 45 to 76 ppm K. Five of the eight trials showed significant yield increases from K fertilization and one other trial had near significant yield increases from K fertilization. In the five K-responsive trials, rice receiving no fertilizer K produced 62% to 95% of the maximum yield produced by rice fertilized with K. The two trials that did not respond to K fertilization both were on the site having the highest soil-test K of the short-term trials. In the three adjacent pure-line and hybrid trials, the grain yield of the hybrid rice was 27 to 34 bu./ac higher than the yield of the pure-line cultivar, but the yield increase from K fertilization ranged from 4 to 19 bu./ac for the hybrid and 8 to 28 bu./ac for the pure-line. These results hint that K fertilization of rice grown on K-deficient soil can result in greater yield increases with pure-line cultivars than hybrid rice cultivars.

Introduction

Soil-test results are used to make fertilizer-potassium (K) recommendations to prevent K deficiency in the planted crop. Delong et al. (2017) reported that 31% of the area cropped to soybean [*Glycine max* (L.) Merr.], the most common crop grown in rotation with rice, had Mehlich-3 soil-test K concentrations considered either low (61–90 ppm) or very low (<61 ppm) and might benefit from K fertilization when cropped to rice in Arkansas. Proper K fertilization of rice has resulted in maximum yield increases ranging from 6 to 51 bu./ac showing how the identification of K-deficient soils and proper fertilization can greatly increase yields (Slaton et al., 2009). Grain yield increases from K fertilization are generally less than 10%, but sometimes as great as 30%, often because of the role K plays in plant tolerance to some diseases (Slaton et al., 2009). Most of the K fertilization research done in Arkansas has focused on pure-line rice response to K fertilization, with only a few trials examining hybrid rice response to fertilization. Dobermann and Fairhurst (2000) generalized that hybrids need more available K than pure-line cultivars due to their greater K demand from greater biomass production than pure-lines. They also suggested that hybrids have a narrower optimal nitrogen (N) to K ratio than pure-line cultivars. Our research objective was to explore the yield response of hybrid and pure-line rice cultivars to K fertilization.

Procedures

In 2019, 6 short-term (single year) field experiments were established at the University of Arkansas System Division of Agriculture's Pine Tree Research Station (PTRS, Colt, Arkansas) and 2 long-term K fertilization trials, 1 located at the Rice Research and Extension Center (RREC; Stuttgart, Arkansas) and 1 at the PTRS, were continued. Selected soil chemical properties and the soil series at each site are listed in Table 1. Composite soil samples (0–4 inches deep) were collected prior to fertilization and planting from each no fertilizer-K control plot in each short-term experiment and from every plot in the two long-term trials. Analysis performed on soil samples included soil pH (1:2 soil:water mixture), Mehlich-3 extractable soil nutrients, and, for the 0 lb K_2O/ac plots, soil organic matter (Table 1). The individual plot size differed among trials with plots measuring 25 ft wide (four 9-row drill passes) by 16 ft long in Trial A, 13 ft wide (two 9-row drill passes) by 20 ft long in Trials B to G, and 15 ft wide by 25 ft long in Trial H (two 8-row drill passes). Plots were seeded with either a pure-line (Diamond or CL153) or hybrid (RT Gemini 214 CL) long-grain cultivar (Table 2). The 6 short-term trials were located in three fields planted with the pure-line and hybrid cultivars planted in adjacent areas (Trials B and C; D and E; and F and G) within the same field that shared similar numerical soil-test values. Each trial had either 5 or 6 replicates of the K fertilization rates ranging from 0 to 160 lb K_2O/ac that were applied preplant as muriate of potash. The 2 long-term trials have the K rates applied every year to the same plots, while the short-term trials were only established for use in the 2019 growing season. Plots in all of the trials received a uniform nutrient application of 46 lb P_2O_5/ac as triple superphosphate broadcast on the soil surface prior to planting, and urea, broadcast at a rate of 100 to 130 lb N/ac prior to flooding at the 5-leaf stage. At each trial, within 2 days after preflood-N application, a flood was established and then maintained until prior to harvest. The middle 5 rows of each plot in each drill pass of Trials A–G or all 8 rows of drill pass in Trial H were harvested with a small plot combine, and grain weights were standardized to a uniform moisture content of 12% to calculate final grain yield for statistical analysis.

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

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

All trials were a randomized complete block design with 5 (Trials A, B, D, and F) or 6 (C, E, G, and H) blocks where K rate was a fixed effect and block was considered a random effect. Analysis of variance was performed on grain yield data from each trial using the GLIMMIX procedure of SAS v. 9.4 (SAS Institute, Inc., Cary, N.C.). Significant mean yield differences from K fertilization were compared using LSMEANS ($\alpha = 0.10$).

Results and Discussion

Grain yield was significantly increased by K fertilization in 5 of the 8 trials (A, B, C, D, and E; Table 2). Three of the 5 K-responsive trials were planted with a pure-line cultivar (Trials A, B, and D) and fertilization with 80 to 160 lb K_2O/ac generally produced the same near-maximum yields that were greater than the yield of rice receiving no fertilizer K. Two of the 3 trials planted with the hybrid cultivar (Trials C and E) responded positively to K fertilization requiring 50 (Trial E) or 100 (Trial C) lb K_2O/ac to maximize yield. The relative yields in the 5 K-responsive trials ranged from 62% to 95% of the maximum mean yield resulting in numerical yield increases of 19 to 70 bu./ac due to K fertilization. The responsive pure-line trials produced between 62% to 88% of the maximum mean yield with the hybrid responsive trials between 90% and 95%. In the 3 nonresponsive trials (Trials F, G, and H), the relative yields of rice receiving no fertilizer-K were 93% and 98% of the maximum mean yield with 4 to 13 bu./ac separating the minimum and maximum yielding treatments. These yield responses to K fertilization and soil-test K are comparable to the results from previous research (Slaton et al., 2009; Fryer et al., 2019; Gruener et al., 2019).

The yield responses in the 3 sites that had a pure-line cultivar planted adjacent to a hybrid cultivar are of special interest because the soil-test K was very low or low (Table 1) and yield increases from K fertilization were expected at these sites and occurred at all but the highest soil-test K location of Trials F and G (Table 2). The question is whether hybrids and pure-lines require different soil-test K, fertilizer-K rates, or both to produce maximum yields. The yield results from these adjacent trials were not statistically compared, but the maximum yield of the hybrid rice was 10 to 30 bu./ac higher than the pure-line cultivar. The grain yield of rice receiving no fertilizer K between the adjacent trials differed by 27 to 34 bu./ac, suggesting that the hybrid may be less responsive to K fertilization and less affected by low soil-K availability than the pure-line cultivar.

The 2 long-term K trials (A and H) had significant (A) or near significant (H) yield differences among the annually applied fertilizer-K rates (Table 2). In Trial A, established in 2001, application of 80 lb K_2O/ac produced maximal statistical yield, but numerically the yields were maximized from an annual application of 120 or 160 lb K_2O/ac. In Trial H, established in 2007, an annual application of 40 to 160 lb K_2O/ac (Table 2) produced maximal yields which, based on single-degree-of-freedom contrasts ($P = 0.0245$), was significantly greater than the yield of rice receiving no fertilizer-K. Grain yield differences among the annual-K rates are just now beginning to become evident in Trial H.

Practical Applications

These yield results suggest that hybrid and pure-line cultivars may respond differently to soil-K availability and have slightly different K fertilization needs with hybrids being less sensitive to low K availability. Despite the hybrid rice producing greater numerical grain yields (e.g., greater K demand) than the pure-line cultivar planted in an adjacent area, the hybrid tended to be less responsive to K fertilization with regard to the magnitude of yield increase from K fertilization than the pure-line cultivar. This observation warrants additional research to determine whether the trend between the hybrid and pure-line cultivars described here for 2019 and similar observations for 2018 (Gruener et al., 2019) are consistent and, if the results are consistent, to examine why. There were only 3 cultivars, Diamond, CL153, and RT Gemini 214 CL, represented in the 2018 and 2019 research, and we assume that each cultivar is representative of other pure-line and hybrid cultivars that are available to growers. The long-term trials at the PTRS are well suited for this purpose since they contain adequate space to plant hybrid and pure-line cultivars in adjacent plots and contain a range of different soil-test K concentrations due to nearly 20 years of fertilization.

Acknowledgments

This research was funded by the Arkansas Rice Check-off Program from funds administered by the Arkansas Rice Research and Promotion Board, Fertilizer Tonnage Fees, and the University of Arkansas System Division of Agriculture. We also acknowledge RiceTec, Inc., for providing the hybrid seed used in these trials.

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Table 1. Selected soil chemical property means (0–4 inch depth, $n = 4$ to 6) from 8 trials used to evaluate rice response to different K fertilization rates at the University of Arkansas System Division of Agriculture's Pine Tree Research Station (PTRS) near Colt, Arkansas and the Rice Research and Extension Center (RREC) near Stuttgart, Arkansas, in 2019.

Trial	Soil series	Fertilizer K rate	Soil pH†	Soil OM	Mehlich-3 extractable soil nutrients				
					P	K	Ca	Mg	Zn
		lb K_2O/ac	---------%---------		------------------------ppm------------------------				
A‡	Calhoun	0	8.1	2.8	38	47	3394	437	7.3
		40	8.3	-	30	53	3382	422	6.4
		80	8.0	-	31	63	3232	437	6.9
		120	8.1	-	31	73	3221	420	6.7
		160	8.1	-	30	78	3180	432	7.6
B	Calloway / Calhoun	0	7.5	2.5	12	58	1922	262	1.3
C	Calloway / Calhoun	0	7.5	2.6	10	50	1761	259	1.3
D	Calhoun	0	7.8	2.3	9	46	2123	334	1.5
E	Calhoun	0	7.9	2.4	10	45	2179	343	1.6
F	Calhoun	0	7.9	2.0	21	64	1977	237	6.6
G	Calhoun	0	7.9	2.1	19	64	1678	257	6.8
H‡	Dewitt	0	5.6	2.4	49	76	984	146	8.7
		40	5.5	-	44	85	922	134	8.3
		80	5.4	-	43	109	886	131	7.6
		120	5.5	-	44	136	862	129	7.4
		160	5.4	-	46	164	846	126	7.6

† Soil pH measured in a 1:2 soil: water mixture, OM, organic matter weight loss on ignition.

‡ Trials A and H are long-term trials where the same fertilizer-K rates are applied annually resulting in different soil-test K among treatments.

Table 2. Rice grain yield as affected by fertilizer-K rate from 8 field trials at the University of Arkansas System Division of Agriculture's Pine Tree Research Station (PTRS) near Colt, Arkansas and the Rice Research and Extension Center (RREC) near Stuttgart, Arkansas, in 2019.

Site	Cultivar	Fertilizer-K rate (lb K_2O/ac)					*P*-value
		0	40–50	80–100	120	150–160	
		--bu./ac--					
A	Diamond†	114 c‡	155 b	175 a	185 a	184 a	<0.0001
B	Diamond	141 c	153 bc	156 ab	159 ab	169 a	0.0551
C	Gemini	170 b	176 ab	179 a	-	179 a	0.0478
D	Diamond	140 c	148 bc	156 ab	144 c	160 a	0.0040
E	Gemini	167 b	181 a	184 a	-	186 a	0.0317
F	Diamond	172	170	173	173	180	0.5778
G	Gemini	206	210	207	-	206	0.5614
H	CL153	167	175	180	180	178	0.1442

† Diamond = pure-line variety; Gemini (RT Gemini 214 CL) = hybrid; CL153 = pure-line variety.

‡ Values in the same row followed by different letters are significantly different ($P < 0.10$).

2019 Rice Grower Research and Demonstration Experiment Program

K.F. Hale[1] and J.T. Hardke[1]

Abstract

In 2019, the Rice Grower Research and Demonstration Experiment (GRADE) Program was conducted in commercial rice fields at 8 locations across Arkansas. Trials consisted of replicated, large-block demonstrations evaluating varieties, nitrogen management, and seeding rates. The University of Arkansas System Division of Agriculture and the Arkansas Rice Research and Promotion Board first initiated this program in 2017 to conduct large block replicated field trials 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 using large block plots of approximately one-half acre or larger within a grower's field to achieve program goals.

Introduction

The Rice Grower Research and Demonstration Experiment (GRADE) Program has continued to grow and develop since its limited start 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 of the GRADE program is to coordinate and demonstrate large-scale plots to validate the performance of rice recommendations and cultivars in commercial production fields across the Arkansas production region. This program is focused on an overall goal of increasing confidence and visibility of research as well as bridging the gap between small-plot research trials and whole-field verification program demonstrations.

The individual goals of the Rice GRADE Program are 1) to conduct large-scale trials on commercial rice farms; 2) to increase large-plot research data on cultivar performance, seeding rate, nitrogen (N) rate and timing, etc.; 3) to arrange hands-on training of agents, consultants, and growers; and 4) to 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 would allow more proactive participation by county agents, consultants, and others while providing multiple sites for educational field events. Additional benefits would also 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 profit.

Procedures

Prior to planting, 8 fields were selected for participation in the Rice GRADE Program for the 2019 season. Trials in 2019 included: 1) Clay Co. variety demonstration; 2) Jefferson Co. variety demonstration; 3) Lawrence Co. variety demonstration; 4) Lee Co. variety demonstration; 5) Greene Co. N rate demonstration; 6) Woodruff Co. N rate demonstration; 7) Lonoke Co. seeding rate demonstration; and 8) Clark Co. seeding rate demonstration. A randomized complete block design with a minimum of 4 replications was used in the implementation of all trials.

Four variety demonstrations were planted, including the cultivars Diamond, LaKast, and Roy J. Variety demonstrations were seeded with a John Deere 6120E tractor used to pull an 8-ft Great Plains no-till box drill. Based on equipment size and field layout, each variety demonstration plot ranged in size from 24 to 40 ft wide and 500 to 600 ft in length. Cooperator equipment was used to implement the seeding rate and N-fertilizer rate demonstrations, and plot size varied based on producer equipment and field layout, with each plot ranging in size from 24 to 40 ft wide and 150 to 1500 ft in length.

Throughout the growing season, related data were collected during routine visits monitoring growth and development of the crop by the program coordinator. In addition to the needed input from the program coordinator, county agent, and rice extension agronomist, the overall management of the trial area is based on normal grower practices.

The 4 variety demonstrations (Clay, Jefferson, Lawrence, and Lee Counties) compared the varieties Diamond, LaKast, and Roy J planted at the standard recommended seeding rate. The Greene Co. N-rate demonstration evaluated the use of the GreenSeeker handheld for determining midseason N needs for the cultivar RT CLXP4534. Two treatments included a single preflood N rate (104 lb N/ac) and the single preflood N rate (104 lb N/ac) followed by a midseason N application (46 lb N/ac) as recommended after evaluation using the GreenSeeker handheld. The Woodruff Co. N-rate demonstration compared a single preflood N rate (145 lb N/ac) based on Nitrogen Soil Test for Rice (N-STaR) to the grower's standard two-way split (106 lb N/ac preflood followed by 46 lb N/ac midseason) approach. The Lonoke Co. seeding rate demonstration compared RT XP760 seeded at 11, 16, 21, and 26

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[1] Program Associate and Rice Extension Agronomist, Department of Crop, Soil, and Environmental Sciences, Stuttgart.

lb seed/ac. The Clark Co. seeding rate demonstration compared RT XP753 seeded at 13, 18, 23, and 28 lb seed/ac.

Harvest was completed with cooperator combine harvesters and weights collected with a weigh wagon. Grain yield was corrected to 12% moisture and reported in bushels per acre (bu./ac). Samples were collected to evaluate harvest moisture and test weight, then dried to 12% moisture to evaluate for milling yields as percent head rice (%HR) and total milled rice (%TR) reported as %HR/%TR. Data were analyzed using PROC GLM in SAS v. 9.4 (SAS Institute, Inc., Cary, N.C.) and means separated using Fisher's least significant difference (0.10).

Results and Discussion

In the Clay County variety demonstration, Diamond and Roy J produced significantly higher yields compared to LaKast (Table 1). In addition, Diamond and Roy J also had significantly higher harvest moisture, head rice yield, and total milled rice yield compared to LaKast. It should be noted that sheath blight disease was severe in areas of the field, and LaKast appeared most affected. No fungicide application was made by the grower for management of the disease. Overall harvest moisture was low (less than 12%), which may have contributed to lower than expected grain yields at this location. Clay County had the lowest average yields of the 4 variety demonstration locations.

In the Jefferson County variety demonstration, Diamond and Roy J had significantly greater yields compared to LaKast (Table 2). Harvest moisture significantly differed among all three varieties, ranging from highest to lowest moisture of LaKast, Diamond, and Roy J, respectively. LaKast and Roy J also had significantly higher head rice yields compared to Diamond at this location.

At Lawrence County, all 3 varieties produced similar grain yields in the variety demonstration (Table 3). The only significant difference noted at this location was higher head rice yield for LaKast compared to Diamond.

In Lee County, the variety demonstration showed significantly higher yields for Diamond compared to both LaKast and Roy J (Table 4). LaKast produced significantly higher head rice yields compared to Diamond and Roy J. Lee County produced the highest overall grain yields of the 4 variety demonstrations.

At Greene Co., the N-rate demonstration evaluated RT CLXP4534 with N applications consisting of 225 lb N/ac preflood across the entire field (Table 5). GreenSeeker handhelds were used to evaluate the need for midseason N applications to maximize grain yield. Based on the response index (the difference between heavily fertilized reference plots and the overall field) exceeding 1.15, an additional 46 lb N/ac was applied at midseason in alternating strips across the field to be harvested individually. The utilization of a midseason nitrogen application produced significantly higher grain yields when compared to no midseason application.

At Woodruff Co., a noticeable phosphorus deficiency was detected later in the season, which may explain lower than expected grain yields (Table 6). Due to the way plot harvest was conducted, statistical analysis of results was not possible. However, the preflood plus midseason application did result in numerically higher grain yields compared to the single preflood application.

The Lonoke Co. seeding rate demonstration evaluated RT XP760 seeded at 11, 16, 21, and 26 lb seed/ac (Table 7). The 21 and 26 lb/ac seeding rates had significantly greater plant stands compared to the 11 and 16 lb/ac seeding rates. However, there were no significant differences in grain yield or harvest moisture across seeding rates in this trial. Glyphosate drift from an adjacent field contributed to stand variability at this location.

The Clark Co. seeding rate demonstration evaluated RT XP753 seeded at 13, 18, 23, and 28 lb seed per acre (Table 8). There was a significant difference in %HR between seeding rates. However, there were no significant differences in plant stand, grain yield, or harvest moisture across seeding rates in this trial.

Practical Applications

Data collected from the 2019 Rice GRADE Program provides support for data generated from small-plot research in regard to variety performance, seeding rate recommendations, and nitrogen management.

Acknowledgments

This research is supported by grower 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. The authors wish to thank all cooperating producers for their assistance with the program this year. We would also like to thank the following county agents who made this work possible: Dave Freeze, Brett Gordon, Keith Perkins, Amy Simpson, Stan Baker, Stewart Runsick, Kurt Beatty, Bryce Baldridge, and Courtney Sisk.

Table 1. Rice Grower Research and Demonstration Experiment (GRADE) Program Clay Co. Variety Demonstration near Corning, Arkansas in 2019.

Cultivar	Harvest Moisture	Test Weight	Grain Yield	Head Rice	Total Rice
	(%)	(lb/bu.)	(bu./ac)	(%HR)	(%TR)
Diamond	11.8	39.6	140.8	48.2	64.8
Lakast	10.7	39.4	86.8	29.6	53.9
Roy J	11.5	40.4	136.3	53.9	68.0
P-value	0.047	0.516	<0.0001	0.001	0.004
CV	4.42	4.26	5.92	11.33	6.03
$LSD_{0.10}$[b]	0.70	NS	9.9	6.83	5.15

[a] Means within a column followed by the same letter are not significantly different ($P > 0.1$).

[b] LSD = least significant difference.

[c] NS = not significant.

Table 2. Rice Grower Research and Demonstration Experiment (GRADE) Program Jefferson Co. Variety Demonstration near Altheimer, Arkansas in 2019.

Cultivar	Harvest Moisture	Test Weight	Grain Yield	Head Rice	Total Rice
	(%)	(lb/bu.)	(bu./ac)	(%HR)	(%TR)
Diamond	17.1	45.7	171.1	56.3	67.9
Lakast	18.0	45.4	161.9	59.2	69.0
Roy J	16.4	46.2	170.7	58.3	68.9
P-value	0.002	0.418	0.016	0.044	0.131
CV	2.12	1.79	2.08	2.24	1.08
$LSD_{0.10}$[b]	0.5	NS	4.8	1.78	NS

[a] Means within a column followed by the same letter are not significantly different ($P > 0.1$).

[b] LSD = least significant difference.

[c] NS = not significant.

Table 3. Rice Grower Research and Demonstration Experiment (GRADE) Program Lawrence Co. Variety Demonstration near Minturn, Arkansas in 2019.

Cultivar	Harvest Moisture	Grain Yield	Head Rice	Total Rice
	(%)	(bu./ac)	(%HR)	(%TR)
Diamond	14.6	149.7	54.7	68.5
Lakast	14.9	148.0	59.6	69.1
Roy J	14.3	149.7	57.0	69.7
P-value	0.452	0.889	0.070	0.116
CV	4.69	3.92	4.14	0.98
$LSD_{0.10}$[b]	NS	NS	3.25	NS

[a] Means within a column followed by the same letter are not significantly different ($P > 0.1$).

[b] LSD = least significant difference.

[c] NS = not significant.

Table 4. Rice Grower Research and Demonstration Experiment (GRADE) Program Lee Co. Variety Demonstration near Moro, Arkansas in 2019.

Cultivar	Harvest Moisture	Test Weight	Grain Yield	Head Rice	Total Rice
	(%)	(lb/bu.)	(bu./ac)	(%HR)	(%TR)
Diamond	13.6	45.1	190.0	56.5	68.5
Lakast	13.8	45.9	175.6	57.9	68.8
Roy J	14.0	45.1	173.3	56.5	68.2
P-value	0.150	0.241	0.036	0.040	0.446
CV	2.49	1.35	3.39	0.98	0.86
$LSD_{0.10}$[b]	NS	NS	9.10	0.84	NS

[a] Means within a column followed by the same letter are not significantly different ($P > 0.1$).

[b] LSD = least significant difference.

[c] NS = not significant.

Table 5. Rice Grower Research and Demonstration Experiment (GRADE) Program Greene Co. Nitrogen Rate Demonstration near Delaplaine, Arkansas in 2019.

Application	Harvest Moisture	Test Weight	Grain Yield	Head Rice	Total Rice
	(%)	(lb/bu.)	(bu./ac)	(%HR)	(%TR)
Preflood N (104 lb N/ac)	15.9	40.7	124.7	47.0	68.7
Preflood N (104 lb N/ac) FB Midseason (46 lb N/ac)	15.0	42.0	154.9	46.4	69.1
P-value	0.251	0.093	0.006	0.555	0.197
CV	5.79	1.93	4.41	2.75	0.56
LSD$_{0.10}$[b]	NS	NS	10.2	NS	NS

[a] Means within a column followed by the same letter are not significantly different ($P > 0.1$).

[b] LSD = least significant difference.

[c] NS = not significant.

Table 6. Rice Grower Research and Demonstration Experiment (GRADE) Program Woodruff Co. Nitrogen Rate Demonstration near Fair Oaks, Arkansas in 2019.

Application[a]	Harvest Moisture	Test Weight	Grain Yield	Head Rice	Total Rice
	(%)	(lb/bu.)	(bu./ac)	(%HR)	(%TR)
Single Preflood	15.9	45.5	132.9	44.9	65.7
Preflood + Midseason	14.8	45.5	137.7	42.7	65.1

[a] Single preflood N rate of 145 lb N/ac; preflood + midseason N rates of 106 lb N/ac + 46 lb N/ac.

Table 7. Rice Grower Research and Demonstration Experiment (GRADE) Program Lonoke Co. Seeding Rate Demonstration near Humnoke, Arkansas in 2019.

Seed Rate (lb seed/ac)	Harvest Moisture	Plant Stand	Grain Yield	Head Rice	Total Rice
	(%)	(plants/ft^2)	(bu./ac)	(%HR)	(%TR)
11	17.5	2.5	182.7	57.3	72.0
16	16.6	2.5	182.0	53.1	71.2
21	16.4	5.0	179.8	51.3	71.2
26	16.4	6.4	179.6	50.2	71.5
P-value	0.011	0.0088	0.959	0.572	0.369
CV	2.48	34.80	5.51	14.03	0.96
LSD$_{0.10}$[b]	0.54	1.85	NS	NS	NS

[a] Means within a column followed by the same letter are not significantly different ($P > 0.1$).

[b] LSD = least significant difference.

[c] NS = not significant.

Table 8. Rice Grower Research and Demonstration Experiment (GRADE) Program Clark Co. Seeding Rate Demonstration near Arkadelphia, Arkansas in 2019.

Seed Rate (lb seed/ac)	Harvest Moisture	Plant Stand	Grain Yield	Head Rice	Total Rice
13	(%)	(plants/ft^2)	(bu./ac)	(%HR)	(%TR)
18	22.1	2.8	187.2	60.7	68.1
23	23.0	5.3	186.7	61.7	69.1
28	22.5	5.4	179.8	58.8	67.0
P-value	0.711	0.1261	0.322	0.033	0.140
CV	6.06	46.51	8.99	1.85	1.60
LSD$_{0.10}$[b]	NS	NS	NS	1.45	NS

[a] Means within a column followed by the same letter are not significantly different ($P > 0.1$).

[b] LSD = least significant difference.

[c] NS = not significant.

Arkansas Rice Performance Trials, 2017-2019

*J.T. Hardke,[1] D.L. Frizzell,[1] E. Castaneda-Gonzalez,[1] T.D. Frizzell,[1] K.F. Hale,[1] T.L. Clayton,[1]
K.A.K. Moldenhauer,[1] X. Sha,[1] E. Shakiba,[1] Y. Wamishe,[2] D.A. Wisdom,[1] J.A. Bulloch,[1] T. Beaty,[1]
D. McCarty,[1] S. Runsick,[3] M. Duren,[4] M. Mann,[4] S.D. Clark,[5] and A. Ablao[5]*

Abstract

The Arkansas Rice Performance Trials (ARPTs) are conducted each year to evaluate promising experimental lines from the Arkansas rice breeding program and commercially available cultivars from public and private breeding programs. The ARPTs are planted on experiment stations and cooperating producer's fields in a diverse range of environments, soil types, and agronomic and pest conditions. The ARPTs were conducted at 4 locations during 2019. Averaged across locations, grain yields were highest for the commercial cultivars RT 7301, RT XP753, RT 7501, RT 7521 FP, DGL263, RT Gemini 214 CL, RT 7321 FP, Jupiter, Titan, and RT CLXL745. Cultivars with the highest overall milling yields during 2019 included: PVL02, CLJ01, Jazzman-2, ARoma 17, Jupiter, CL151, CL153, and CLM04.

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 Performance Trials (ARPTs) are conducted each year to compare promising new experimental lines and newly released cultivars from the breeding programs in Arkansas, Louisiana, Texas, Mississippi, and Missouri 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 4 locations for the 2019 ARPTs included the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC) near Stuttgart, Arkansas; the Pine Tree Research Station (PTRS) near Colt, Arkansas; the Northeast Research and Extension Center (NEREC) near Keiser, Arkansas; and the Trey Bowers farm in Clay County (CLAY). Seventy-five entries, including established cultivars and promising breeding lines, were grown across a range of maturities.

The studies were seeded at RREC, PTRS, NEREC, and CLAY on 18 April, 16 May, 30 April, and 3 April, respectively. Pure-line cultivars (varieties) were drill-seeded at a rate of 35 seed/ft^2 in plots 8 rows (7.5-in. spacing) wide and 16.5 ft in length. Hybrid cultivars were drill-seeded into the same plot configuration using a seeding rate of 12 seed/ft^2. Cultural practices varied somewhat among the ARPT locations but overall were grown under conditions for high yield. Phosphorus and potassium fertilizers were applied before seeding at the RREC and PTRS locations. Nitrogen was applied to ARPT studies located on experiment stations at the 4- to 5-leaf growth stage in a single pre-flood application of 130 lb N/ac on silt loam soils and 160 lb N/ac on clay soils using urea as the N source. The permanent flood was applied within 2 days of preflood N application and maintained throughout the growing season. At maturity, the center 4 rows of each plot were harvested, the moisture content and weight of the grain were determined, and a subsample of harvested grain 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 4 replications.

Results and Discussion

The 3-year average of agronomic traits, grain yields, and milling yields of selected cultivars evaluated during 2017–2019 are listed in Table 1. The top-yielding entries, averaged across 3 study years, include: RT 7501, RT 7521 FP, RT Gemini 214 CL, RT XP753, RT 7321 FP, Lynx, Jupiter, and CLL16, with grain yields of 237, 230, 230, 230, 226, 209, 207, and 206 bu./ac, respectively. In regard to percent head rice and percent total

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[1] Rice Extension Agronomist, Program Associate, Program Associate, Program Technician, Program Associate, Program Associate, Professor, Professor, Assistant Professor, Program Associate, Program Associate, Program Associate, and Program Associate, respectively, Department of Crop, Soil, and Environmental Sciences, Stuttgart.

[2] Associate Professor, Department of Plant Pathology, Stuttgart.

[3] Clay Co. Agriculture Agent, Corning.

[4] Resident Director, Program Technician, Northeast Research and Extension Center, Keiser.

[5] Resident Director, Research Program Technician, Pine Tree Research Station, Colt.

white rice (%HR/%TR), Jazzman-2, CL153, ARoma 17, Jewel, CLL15, and CL151 had the highest overall average milling yields from 2017–2019.

Selected agronomic traits, grain yield, and milling yields from the 2019 ARPT are shown in Table 2. Grain yield averaged across all locations and cultivars was 207 bu./ac. The cultivars RT XP753, RT 7501, RT 7521 FP, DGL263, RT Gemini 214 CL, and RT 7321 FP were the only ones to maintain a grain yield above 200 bu./ac at all locations. Other notable cultivars in 2019 included RT 7301, Jupiter, Titan, RT CLXL745, Lynx, CLM04, CL272, and CLL15. Milling yield, averaged across locations and cultivars, was 59/70 (%HR/%TR) during 2019. The cultivars PVL02, CLJ01, Jazzman-2, ARoma 17, and Jupiter had the highest milling yields of all commercial entries averaged across locations.

The most recent disease ratings for each cultivar are listed in Table 3. Ratings for disease susceptibility should be evaluated critically to optimize cultivar selection. These ratings should not be used as an absolute predictor of cultivar performance with respect to a particular disease in all situations. Ratings are a general guide based on expectations of cultivar reaction under conditions that strongly favor disease; however, the environment will modify the actual reaction in different fields.

Growers are encouraged to seed newly released cultivars on a small acreage to evaluate performance under their specific management practices, soils, and environment. Growers are also encouraged to seed rice acreage in several cultivars to reduce the risk of disease epidemics and environmental effects. Cultivars that have been tested under Arkansas growing conditions are more likely to reduce potential risks associated with crop failure.

Practical Applications

Data from this study will assist rice producers in selecting cultivars suitable for the wide range of growing conditions, yield goals, and disease pressure found throughout Arkansas.

Acknowledgments

The authors wish to thank all Arkansas rice growers for financial support of the Arkansas Rice Performance 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. We wish to thank Chuck Pipkins for his dedication to making the ARPT possible.

Table 1. Results of the Arkansas Rice Performance Trials averaged across the three-year period of 2017–2019.

Cultivar	Grain length[a]	Straw strength rating[b]	50% Heading[c]	Plant height	Test weight	Milled kernel weight[d]	Chalky kernels[d]	Milling yield by year				Grain yield by year			
								2017	2018	2019	Mean	2017	2018	2019	Mean
			(days)	(in.)	(lb/bu.)	(mg)	(%)	---(% head rice/% total rice)---				--------------(bu./ac)--------------			
ARoma 17	LA	1.0	87	36	39.6	22.0	1.35	62/71	56/70	63/70	**60/70**	176	164	178	**173**
CL151	L	1.3	83	34	39.7	20.4	3.07	58/70	54/70	62/71	**58/70**	191	185	205	**194**
CL153	L	1.0	86	34	39.7	20.3	1.42	61/71	58/70	62/71	**60/70**	185	183	189	**186**
CL272	M	1.0	86	35	39.9	22.2	2.18	52/68	49/70	58/70	**53/69**	193	183	207	**194**
CLL15	L	1.0	86	33	39.7	21.3	1.93	58/70	56/70	59/69	**58/70**	190	192	206	**196**
CLL16	L	1.0	86	36	39.6	22.2	1.72	--	50/69	55/68	**53/69**	--	207	205	**206**
CLM04	M	1.1	87	37	39.0	21.9	2.22	58/68	51/69	62/69	**57/69**	202	205	208	**205**
Diamond	L	1.0	86	37	39.7	21.4	1.68	56/69	52/69	58/70	**56/70**	206	206	204	**205**
Jazzman-2	LA	1.1	84	31	40.0	20.5	0.72	--	57/70	64/71	**61/70**	--	140	159	**149**
Jewel	L	1.0	87	37	39.7	19.9	1.41	59/71	57/70	61/71	**59/70**	192	186	184	**187**
Jupiter	M	1.0	87	34	38.8	21.4	2.08	59/67	53/69	63/68	**58/68**	203	199	218	**207**
LaKast	L	1.3	84	37	40.1	22.3	1.43	56/70	53/67	58/70	**56/69**	188	187	198	**191**
Lynx	M	1.1	87	35	39.5	23.8	2.06	53/67	49/69	59/69	**54/69**	206	205	215	**209**
PVL01	L	1.0	89	33	39.4	21.8	0.95	57/70	53/69	61/70	**57/70**	163	162	175	**167**
RT 7321 FP	L	1.3	79	38	407	22.2	1.74	--	48/70	55/71	**51/70**	--	214	237	**226**
RT 7501	L	1.1	83	35	40.1	21.3	0.96	--	52/70	58/70	**55/70**	--	235	240	**237**
RT 7521 FP	L	1.3	82	38	40.5	21.2	2.28	--	54/69	58/70	**56/69**	--	220	240	**230**
RT CLXL745	L	1.7	80	37	40.2	22.4	2.49	52/70	52/70	57/71	**54/70**	202	190	217	**203**
RT Gemini 214 CL	L	1.3	85	39	39.9	20.7	2.87	56/69	53/69	57/70	**55/69**	215	235	239	**230**
RT XP753	L	1.1	82	37	40.2	21.2	2.17	49/70	49/71	56/71	**52/71**	220	229	242	**230**
Titan	M	1.1	81	34	39.6	22.6	1.80	51/68	46/70	59/69	**52/69**	200	192	218	**204**
ARX6-1010	L	1.3	85	38	40.1	20.8	1.96	55/1	54/70	59/71	**56/70**	200	200	203	**201**
ARX7-1084	L	1.0	89	35	39.6	21.8	2.53	57/69	54/69	56/70	**56/69**	210	201	206	**206**
Mean		**1.1**	**85**	**36**	**39.8**	**21.5**	**1.87**	**56/69**	**52/69**	**59/70**	**56/70**	**197**	**197**	**208**	**201**

[a] Grain length: L = long-grain; M = medium-grain.

[b] Relative straw strength based on field tests using the scale: 1 = very strong straw, 5 = very weak straw; based on percent lodging.

[c] Number of days from plant emergence until 50% of the panicles are visibly emerging from the boot.

[d] Data from Riceland Grain Quality Lab, 2016–2018. Based on weight of 1000 kernels.

Table 2. Results of the Arkansas Rice Performance Trials at four locations during 2019.

							Grain yield by location and seeding date				
Cultivar	**Grain length[a]**	**Straw Strength rating[b]**	**50% heading[c]**	**Plant height**	**Test weight**	**Milling yield[d]**	**CLAY 3 April**	**NEREC 30 April**	**PTRS 16 May**	**RREC 18 April**	**Mean**
			(days)	**(in.)**	**(lb/bu.)**	**(%HR/%TR)**	--------------------------	--------------------------	**(bu./ac)**	--------------------------	--------------------------
ARoma 17	LA	1.0	85	36	39.9	63/70	203	184	142	181	**178**
CL151	L	1.0	82	34	40.2	62/71	221	208	187	206	**205**
CL153	L	1.0	85	33	39.9	62/71	209	192	168	188	**189**
CL272	M	1.0	85	35	40.3	58/70	212	210	175	231	**207**
CLJ01	LA	1.0	83	32	40.5	65/71	194	174	155	183	**177**
CLL15	L	1.0	84	31	40.4	59/69	224	200	185	214	**206**
CLL16	L	1.0	87	36	39.7	55/68	207	187	193	233	**205**
CLM04	M	1.0	86	37	39.7	62/69	214	208	181	231	**208**
DGL044	L	1.0	88	33	38.5	61/70	188	180	203	254	**206**
DGL263	L	1.5	82	34	39.8	58/68	238	255	209	252	**239**
Diamond	L	1.0	85	35	40.5	58/70	226	193	179	219	**204**
Jazzman-2	LA	1.0	84	32	40.2	64/71	181	174	137	141	**159**
Jewel	L	1.0	85	36	40.1	61/71	189	171	156	220	**184**
Jupiter	M	1.0	86	34	39.0	63/68	200	230	198	246	**218**
LaKast	L	1.0	82	35	40.8	58/70	206	207	167	213	**198**
Lynx	M	1.0	85	34	39.9	59/69	209	229	185	237	**215**
MM17	M	1.0	85	32	39.9	60/69	218	204	159	231	**203**
PVL01	L	1.0	87	32	39.9	61/70	193	164	151	192	**175**
PVL02	L	1.0	83	34	40.4	65/72	191	184	164	179	**180**
RT 3201	M	1.0	78	37	41.1	58/70	194	188	165	217	**191**
RT 7301	L	1.3	82	36	40.8	57/71	255	245	197	274	**243**
RT 7321 FP	L	1.0	79	38	41.2	55/71	256	237	206	248	**237**
RT 7501	L	1.0	84	35	40.2	58/70	240	247	197	274	**240**
RT 7521 FP	L	1.0	82	38	40.8	58/70	253	233	216	256	**240**
RT CLXL745	L	1.3	79	36	41.6	57/71	236	214	192	225	**217**
RT Gemini 214 CL	L	1.0	83	38	40.3	57/70	246	235	212	261	**239**
RT XP753	L	1.0	81	36	40.9	56/71	256	245	201	265	**242**
Titan	M	1.0	80	34	40.0	59/69	242	218	187	226	**218**
ARX6-1010	L	1.3	83	36	40.8	59/71	219	205	170	219	**203**
ARX7-1084	L	1.0	86	34	40.0	56/70	222	197	179	225	**206**
CLX5-4197	L	1.0	85	32	40.4	60/70	194	208	173	208	**196**
CLX6-2097	L	1.0	83	33	40.8	60/69	205	202	182	213	**201**
CLX6-2195	L	1.0	84	32	40.6	61/71	211	197	173	194	**194**
Mean		**1.0**	**84**	**35**	**40.3**	**59/70**	**217**	**207**	**180**	**223**	**207**

[a] Grain length: L = long-grain; M = medium-grain.

[b] Relative straw strength based on field tests using the scale: 1 = very strong straw, 5 = very weak straw; based on percent lodging.

[c] Number of days from plant emergence until 50% of the panicles are visibly emerging from the boot.

Table 3. Arkansas rice cultivar reactions[a] to diseases and lodging (2019).

Cultivar	Sheath Blight	Blast	Straight head	Bacterial Panicle Blight	Narrow Brown Leaf Spot	Stem Rot	Kernel Smut	False Smut	Lodging	Black Sheath Rot
ARoma 17	MS	MS	--	MS	--	--	S	S	MR	--
CL111	VS	MS	S	VS	S	VS	S	S	MS	S
CL151	S	VS	VS	VS	S	VS	S	S	S	S
CL153	S	MS	--	MS	MS	--	S	S	MR	--
CL163	VS	S	--	MS	R	--	MS	--	MS	--
CL172	MS	MS	--	MS	S	--	S	S	MR	--
CLL15	S	MS	--	S	--	--	S	S	MR	--
CLM04	--	S	--	S	--	--	--	S	S	--
Della-2	S	R	MR	MS	MS	--	--	--	--	--
Diamond	S	S	--	MS	MS	S	S	VS	MS	--
Jazzman-2	S	MS	VS	VS	S	--	S	S	MS	--
Jewel	MS	MS	--	MS	MR	--	--	S	MS	--
Jupiter	S	S	S	MR	MR	VS	MS	MS	S	MR
LaKast	MS	S	MS	MS	MS	S	S	S	MS	MS
Lynx	S	MS	--	S	MR	--	--	MS	S	--
PVL01	S	S	--	S	MR	--	VS	VS	MS	--
PVL02	MS	MS	--	S	MS	--	--	--	S	--
Roy J	MS	S	S	S	R	S	VS	S	MR	MS
RT 7301	MS	MR	--	MR	MR	--	--	--	MR	--
RT 7321 FP	MS	--	--	--	--	--	S	MS	S	--
RT 7501	S	--	--	--	--	--	S	S	S	--
RT 7521 FP	S	--	--	--	--	--	MS	VS	S	--
RT CLXL745	S	R	MR	MR	R	S	S	S	S	S
RT Gemini 214 CL	S	MR	--	--	--	--	MS	VS	MS	--
RT XP753	MS	R	MR	MR	R	--	MS	S	MR	S
Titan	S	MS	--	MS	MR	--	MS	MS	MS	--

[a] Reaction: R = Resistant; MR = Moderately Resistant; MS = Moderately Susceptible; S = Susceptible; VS = Very Susceptible. Cells with no values indicate no definitive Arkansas disease rating information is available at this time. Reactions were determined based on historical and recent observations from test plots and grower fields across Arkansas and other rice states in the southern U.S. In general, these ratings represent expected cultivar reactions to disease under conditions that most favor severe disease development.

Table prepared by Y. Wamishe, Associate Professor/Extension Plant Pathologist.

Grain Yield Response of Furrow-Irrigated RiceTec Gemini 214 CL to Different Nitrogen Sources, Irrigation Timing, and Tillage

C.G. Henry,[1] D.M. Pickelmann,[1] J.P. Rix,[1] and G.D. Simpson[1]

Abstract

A study was conducted to evaluate the performance of three different nitrogen (N) fertilizer source treatments in a furrow-irrigated rice field study during 2019 at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center near Stuttgart, Arkansas on a DeWitt silt loam. The N sources used were 32% urea-ammonium nitrate (UAN) solution, Environmentally Smart Nitrogen (ESN), and urea. The N sources were used in several different split application timings. Yield differences between the N treatments were not observed for the hybrid RT 7311 CL ($P = 0.184$). There was no significant difference in yield between no-till and tillage treatments ($P = 0.52$). Irrigation timings ranging between continuously irrigated, every 3 days, 7 days and 10 days resulted in no significant difference in yield ($P = 0.6$).

Introduction

Rice is one of the most important crops in the world, which was consumed by almost 3 billion people worldwide in 2015 (Mosleh et al., 2015). In the United States, Arkansas is the largest producer of rice. In the last three years, Arkansas contributed 48.8% of the total rice production in the U.S. In 2016, 47% of the total rice production and 49.1% of the total rice acreage was represented by Arkansas (Hardke, 2017). Nitrogen (N) fertilizer was applied to 97% of the 2006 Arkansas rice production 1.396 million acres (565,182 ha) at an average rate of 190 lb N/ac (213 kg N/ha) (USDA-NASS, 2013). Needless to say, N application plays a significant role in rice production as well as in the cost associated with it.

In a flood irrigated rice field, 150 lb N/ac is recommended for most rice cultivars which can be adjusted according to the soil texture, cultivar of the rice, and previous crop (Davidson et al., 2016), although tests are available to predict the in-season N needs of rice for mid-South conditions (Roberts et al., 2012). Typically, N is applied through ammoniacal fertilizers like urea or ammonium sulfate. This fertilization can be done as a single application when the plants are at the 4- to 6-leaf stage, or it can be split into 2 applications where the first is applied at the 4- to 6-leaf stage and the latter at the beginning of the reproductive stage (Frizzell et al., 2016; Wilson et al., 1994). Urea is extensively used as the N source for these applications due to its low cost per pound of N (Wilson et al., 1994; Golden et al., 2009). The use of ground operated applicators for applying urea is limited in a flooded field after the construction of levees (Golden et al., 2009). Therefore, aerial application of urea is conducted, which significantly increases the cost of N application (Golden et al., 2009). It also creates a problem of uneven urea distribution in the field (Wilson et al., 1994). This problem possibly can be reduced by using urea-ammonium nitrate (UAN) solution; however, it can be a substandard N source compared to urea for pre-flood application due to the 25% of N as nitrate that can be lost via denitrification in flooded or saturated soil (Wilson et al., 1994). Aerial application can also cause delayed N application during the untimely rainfall events at the time of desired (4- to 6-leaf) rice growth stage. (Golden et al., 1994).

This problem can be marginalized in a furrow-irrigated (row-rice) rice field where the drainage of water from the field is easily manageable, and the ground equipment can be used for fertilizer and chemical application. However, little is known about the types of N fertilizers that can be used in a row-rice production system. In Arkansas, 7.1% of the rice acreage is furrow-irrigated, and it is gaining popularity among farmers because it helps to simplify crop rotation and management such as reduced labor. However, no knowledge of nitrogen efficiency in furrow-irrigated rice is available. Because it is readily available as a liquid, the application of UAN can be made through the irrigation system, likely at a much lower cost than dry fertilizers, in furrow-irrigated rice systems.

Another kind of approach to increase N efficiency is to use controlled release fertilizers like Environmentally Smart Nitrogen (ESN). These types of fertilizers can help to reduce environmental losses by matching nutrient demand of crops with N release from the fertilizer (Blackshaw et al., 2011). It has been suggested in a study (Golden et al., 2009) that N release from ESN is too rapid for rice cultivated in the direct-seeded, delayed-flood cultural system.

Stevens et al. (2020) conducted a study where 3 treatments were used to initiate irrigation based on depleting the available water within 3 effective rooting depths of 6 in., 12 in. and 18 in., managed with a checkbook method mobile app. They found that the 12-in. rooting depth trigger resulted in a significantly higher yield.

Little is known about continuous furrow-irrigated rice or no-till furrow-irrigated rice. Ockerby and Fukai (2001) studied

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

a raised bed continuous furrow irrigation system for 4 pure-line varieties and found that paddy rice had slightly higher yields. They did not find nitrogen to have been a limiting factor but noted that growth was slower than paddy rice. They concluded that water supply in a continuously irrigated furrow system was not a limiting factor.

This experiment was done to study the effects of and approach for using different kinds of N fertilizer in a row-rice field on the crop yield, to evaluate tillage versus no tillage on beds, and irrigation timing.

Procedures

This study was conducted at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center near Stuttgart, Arkansas, in 2019. The soil in the field is predominately a DeWitt Silt loam, which was identified by soil tests conducted by the USDA web soil survey. The field has been in continuous furrow-irrigated rice since 2016 and no-till since 2017 (last year of tillage). Raised beds were constructed on 30-in. spacing using a bedder-roller in 2017. Beds were left intact from the previous year, and stubble was mowed at the height of 4 in., then burned. A furrow runner (Perkins Sales, Bernie, Mo.) was then used to reconstruct a narrow furrow leaving the bed intact. Glyphosate (40 oz/ac) was used to kill any vegetation before planting. RiceTec hybrid Gemini 214 CL was seeded in the field. Fertilizer was applied to the entire field, including 21 lb/ac of ammonium sulfate, 60 lb/ac of potassium, 60 lb/ac of phosphorus, 34 lb/ac of sulfur and 10 lb/ac of zinc. The field was divided into a total of 24 plots of approximately 1 ac size for each treatment. Each plot consisted of 12 beds and 12 furrows (11 plus two half furrows). Each treatment was replicated 3 times and randomized. Rice was seeded at 10% above the standard seeding recommendation, or 29 lb/ac on 30 April. The following 2019 N treatments utilizing urea (46-0-0; N-P_2O_5-K_2O), ESN (44-0-0), and UAN (32-0-0) were applied:

- Urea (150), 150 lb N/ac as urea with a urease inhibitor on June 3 at the 3–4 leaf stage;
- Split Urea (100/50), 100 lb N/ac as urea with a urease inhibitor applied on 4 June and 50 lb N/ac as urea with a urease inhibitor applied on 18 June (14 days post first N application);
- Split ESN/Urea (75/75), 75 lb N/ac as ESN applied on 4 June and 75 lb N/ac as urea with a urease inhibitor applied on 18 June (14 days post first N application);
- Split Urea/ESN (75/75), 75 lb N/ac as urea with a urease inhibitor applied on 4 June and 75 lb N/ac as ESN applied on 18 June (14 days post first N application);
- Split UAN Fertigated (100/50), 100 lb N/ac as UAN applied on 13 June and 50 lb N/ac as UAN applied on 1 July as a second nitrogen application split using fertigation method described above;
- UAN (150), 150 lb N/ac as UAN applied on 13 June along with irrigation using the fertigation method described above;
- Split UAN (100/50/25), 100 lb N/ac of UAN fertigated on 13 June, then another 50 lb N/ac as UAN applied on 1 July. Another 25 lb N/ac was applied as UAN for the next partial irrigation event on 2 July on the top half of the field only (advance time of 5 hours) a full irrigation (advance time 10 hours); and
- Split Urea (100/50/25), 100 lb N/ac as urea with a urease inhibitor applied on 4 June and 50 lb N/ac as urea with a urease inhibitor applied on 18 June, along with an additional 25 lb N/ac on the top half of the field only for the next relevant irrigation event, 19 June.

A fertigation method was designed for UAN application. A "High flo" gold series 25 psi pump was used to pressurize the system. Netafim 2 L/h or 1 L/h emitters were used depending upon the application rate. Standard polyethylene 3/4-in. drip tube was laid at the top of the plots, and emitters were installed in the furrows of the UAN treatment plots. An AMIAD 100 micron 3/4-in. disc filter was used to prevent emitter clogging. The advance time of the irrigation was determined from previous knowledge of advance time in earlier irrigation events. Historically the advance time of the field was 10 hours. The fertigation system was designed to deliver the application rate desired in 8 hours. The fertigation system was started 2 hours after the initiation of the irrigation; and after the wetting front advance, the irrigation was terminated allowing for recession to deliver fertilizer to the tail end of the furrow. The next morning, irrigation recommenced incorporating the UAN into the profile. For the top end only treatment, the irrigation and fertigation were discontinued when the advance reached one-third the furrow distance, and the N fertilizer application began when the irrigation commenced.

The field was furrow-irrigated with a novel tailwater recovery system. End blocking was used to hold a flood on the bottom of the field and allow minimal runoff. Irrigation was applied continuously using lay-flat pipe on the nitrogen and tillage studies. For the irrigation study, irrigation treatments were applied for 24 hours, every 3, 7, and 10 days. A continuously irrigated treatment was also included.

For the tillage study, field cultivator tillage was applied, and beds and furrows were reformed with a bedder-roller just prior to planting. All no-till beds were cleaned out using a furrow runner (Perkins Sales, Bernie, Mo.), a no-till implement designed to form and clean out a small slot in each furrow for improved water conveyance. The tops of the beds were undisturbed. The tillage and irrigation study received 150 lb/ac of urease inhibited urea on 3 June.

A pre-plant herbicide application of 1 pt/ac of Command, 6 oz/ac of Newpath, 1 qt/ac Roundup, and 2 oz/ac of Sharpen was applied the same day after planting on 30 April. The first herbicide post spray application was made on May 16 at a rate of 15 gal/ac with amounts of 1 qt/ac of Prowl and 1 qt/ac Facet. The second herbicide post spray application was made on May 24 with 5 oz/ac of Beyond, 3/4 oz/ac of Permit Plus, and 30 oz/ac of Clincher. The third herbicide post spray application was on 12 June with 5 oz/ac of Newpath. The fourth herbicide post spray was an aerial application on 27 June with 1 oz/ac of Permit Plus. The fifth herbicide post spray was made with a Mud Master ground applicator on 9 July with 1.5 pt/ac of Basagran, 2 qt/ac of Propanil, and 5 oz/ac of Beyond. Aerial application of Ravage Insecticide was applied for rice stink bugs on 8 and 17 August at 4 oz/ac. Irrigation was applied to the field continuously using a novel tailwater recovery system, which applied 11.7 ac-in./ac during the season with an additional 17.25 in. of rainfall.

The GreenSeeker device was used to measure the Normalized Difference Vegetation Index (NDVI) of randomly selected areas of the plant canopy as well as reference strips in each plot during the panicle initiation stage. Reference strips of 5 ft by 5 ft were managed by applying one-third cup extra urea than the rest of the plots. One reference strip each at the top, middle, and bottom positions along the furrow length was set up on the border plot. The response index was calculated by dividing the NDVI value of the reference strip by the NDVI value of plants from the treatment plot for their respective positions along the furrow length.

Analysis of variance was performed using JMP Pro. The measured outcomes were tested by the assumptions of the mathematical model (normality and homogeneity of variance). The factor means for each response variable, when significant, were compared by Tukey's honestly significant difference test at a 5% probability.

Results and Discussion

The Tukey's multiple comparison test indicated no differences ($P = 0.187$) between the 8 N treatments at $\alpha = 0.05$ (Table 1). The advance time during the first irrigation was near 10 hours as expected. The data does not clearly indicate that any fertilizer treatment or split is more advantageous over another. The yields were much higher in 2019 than in 2018 or 2017 when the study was repeated previously.

The response index differences, (reference NDVI/measured NDVI) were compared between treatments. None of the treatments or locations in the field required additional N (highest was 1.1, where 1.2 would indicate a need for additional midseason nitrogen). There was no difference in general in NDVI treatments at the top and bottom of the field. There were differences in the middle of the field, but of the treatments that showed a difference three of those treatment plots had herbicide damage and a thinner stand than the other treatments, and may not actually be different than the rest of the treatment because of this (data not shown).

No differences ($P = 0.52$) between the tillage and no-till treatments were found (Table 2). Differences in yield were significant in 2018. This suggests that after one year, yields may return to normal production. The furrow runner improved irrigation, and the beds had more structure than in 2018.

There was no significant difference in yield ($P = 0.6$) between any of the irrigation treatments (Table 3). Continuously irrigated furrow rice was not significantly different from a 10-day irrigation cycle. The highest yield was observed on a 3-day irrigation cycle of 184.5 bu./ac.

Practical Applications

While preliminary, the tillage study suggests that no-till may be feasible with no yield penalty in a furrow-irrigated rice system. The irrigation study occurred in a relatively wet year but does suggest that a longer cycle than 3 to 5 days may not reduce yield. The variable flow tailwater system performed well and achieved high yields on the field with an 11.7 ac-in./ac of irrigation water requirement. The data suggest that different forms of N may be used in furrow-irrigated rice systems. No treatment and plots required additional midseason N. While incorporating ESN into the program in previous years had resulted in higher yields, this was not the case in 2019. Predicting the advance time when fertigating a field when applying UAN through irrigation is crucial to achieve the optimal distribution of nitrogen throughout the field. No conclusions could be drawn about multiple splits, except for the UAN treatments, no trends or differences could be found that clearly indicated any benefit from multiple N splits. In 2018, there were some differences, but these were attributed to poor uniformity because of dry soil in the 150 UAN treatment.

A similar study was conducted on this same field in the summer of 2017, where no treatment difference was found among the N sources (Kandpal and Henry, 2017). In that study, the weather could be explained as a "wet" year; whereas in the 2018 study, the weather was more characteristic of a "dry" year. The 2019 study would be considered more of a "wet" year. There appears to be an interaction between N and water (both rain and irrigation) and perhaps soil moisture in the yield of furrow-irrigated rice, which warrants study. However from 3 years of study, the data suggest that it may be possible to use different forms of N other than urea or in combination in a furrow-irrigated rice production system without significantly impacting yield. The feasibility of applying UAN fertilizer through the irrigation system requires more development and improved equipment to adjust fertilizer flow rates to match advance times being experienced during a fertigation event, but based on this study appears feasible. More experiments and data are needed to confirm these findings and develop recommendations that can be applied to furrow irrigation systems for rice. From this study, it appears that a no-till furrow-irrigated system can be successful across a wide range of fertilizer types and irrigation scheduling programs.

Acknowledgments

The authors would like to thank the Arkansas Rice Research and Promotion Board and the University of Arkansas System Division of Agriculture for supporting and funding this study. Additionally this material is based upon work that is supported by the Hatch Act and Smith-Lever Act through the National Institute of Food and Agriculture, United States Department of Agriculture.

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Table 1. Yield differences between nitrogen source and application timing revealed by analysis of variance.

Treatment	Yield (bu./ac)
Urea (150)	212.3 a[‡]
Split Urea (100/50)	204.1 a
Split ESN[†]/Urea (75/75)	196.0 a
Split UAN (150/50/25)	194.5 a
Split Urea (100/50/25)	184.1 a
Split UAN (75/75)	182.2 a
UAN (150)	176.6 a
Urea/ESN (75/75)	170.5 a

[†] ESN = Environmentally Safe Nitrogen; UAN = urea ammonium nitrate.

[‡] Means within a column followed by different letters are significantly different at $P = 0.05$ level. Tukey's honestly significant difference method used for mean comparison.

Table 2. Yield differences between tillage and no tillage treatments by analysis of variance.

Treatment	Yield
	(bu./ac)
Tillage	216.1 a[†]
No-Till	209.4 a

[†] Means within a column followed by different letters are significantly different at $P = 0.05$ level. Tukey's honestly significant difference method used for mean comparison.

Table 3. Yield differences between irrigation timing treatments by analysis of variance.

Treatment	Yield
	(bu./ac)
Continuous	179.5 a[†]
Every 3 days	184.8 a
Every 7 days	170.5 a
Every 10 days	165.9 a

[†] Means within a column followed by different letters are significantly different at $P = 0.05$ level. Tukey's honestly significant difference method used for mean comparison

Impact of Row Spacing and Seeding Rate on Rice Grain Yield

M.J. Lytle,[1] J.T. Hardke,[2] T.L. Roberts,[1] D.L. Frizzell,[2] E. Castaneda-Gonzalez,[2] T.D. Frizzell,[2] K.F. Hale,[2] and T.L. Clayton[2]

Abstract

In mid-South rice (*Oryza sativa* L.) production, drill-seeding is the most common planting practice. Novel plant spacing may allow producers to gain grain yield from lower seeding rates due to enhanced plant spacial density and accelerated canopy closure. An experiment evaluating the impact of row spacing on rice grain yield was conducted in the summer of 2019 at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC) near Stuttgart, Arkansas and at the Northeast Research and Extension Center (NEREC) near Keiser, Arkansas. The test consisted of a pure-line cultivar, Diamond, and a hybrid cultivar, RT XP753. Seeding rates for each cultivar included 10, 20, 30, 40, and 50 seed/ft^2 for Diamond and 4, 7, 10, 13, and 16 seed/ft^2 for RT XP753. The two cultivars were planted using drill row spacings of 3.25, 7.5, 10, and 15 inches. The experiment was set up as a two-factor factorial randomized complete block design, with the first factor being row spacing and the second factor being seeding rate. Grain yield data were collected at harvest. The 10-in. row spacing had significantly higher grain yields than all other spacings for Diamond and RT XP753 at the RREC and for RT XP753 at the NEREC. For Diamond at the RREC, the 10-in. row spacing had significantly higher grain yields compared to the 3.25- and 15-in. row spacings, but was not different from the 7.5-in. row spacing. This research suggests that a 10-in. drill row spacing could have the potential to increase yield compared to the more common 7.5-in. drill row spacing.

Introduction

Current Arkansas drill row width recommendations range from 4 to 10 inches, with 7.5 inches being the most commonly used by producers (Hardke et al., 2018). Previous research showed an increase in rice grain yield using a narrower 6- to 8-in. row spacing (Frizzell et al., 2006). Ensuring uniform stand density becomes more significant as rice row width increases. Arkansas and mid-South producers may be more inclined to transition to 10-in. rice row widths because of the time and financial savings associated with 10-in. soybean planter row widths. Research has shown that a significant yield increase also may be the result of narrower soybean row spacing (Ashlock et al., 1994). Also, a 10-in. drill will be less prone to large clay soil masses becoming embedded within the coulters than a 7.5-in. drill. The rice seeding rates for conventional varieties, about 30 seed/ft^2, are sufficient to achieve optimal rice stand density. For hybrid cultivars, 10 to 15 seed/ft^2 are required (Hardke et al., 2018).

Procedures

An experiment was set up to determine the appropriate row spacing and seeding rate for Arkansas rice production. The field experiment was conducted in the summer of 2019 at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC) near Stuttgart, Arkansas and at the Northeast Research and Extension Center (NEREC) near Keiser, Arkansas on a DeWitt silt loam soil and a Sharkey clay soil, respectively. The experiment was set up as a two-factor factorial randomized complete block design, with the first factor being row spacing and the second factor being seeding rate. The experiment was replicated four times. Row spacing treatments were 3.25, 7.5, 10, and 15 inches (in.). Seeding rate treatments for Diamond were 10, 20, 30, 40, and 50 seed/ft^2 and 4, 7, 10, 13, and 16 seed/ft^2 for RT XP753. Rice was planted using a small-plot cone drill. Plot size was 16.5-ft in length and 5-ft in width. At each location, a single preflood nitrogen (N) application was made using rates of 130 lb N/ac at RREC and 160 lb N/ac at NEREC. Additional cultural practices followed University of Arkansas System Division of Agriculture recommendations. At maturity, the center 30 inches of each plot were harvested to determine grain weight and moisture content. This resulted in the harvest of 8 rows in the 3.25-in. row spacing, 4 rows in the 7.5-in. row spacing, 3 rows in the 10-in. row spacing, and 2 rows in the 15-in. row spacing. Rice grain yield was adjusted to 12% moisture and expressed on a bu./ac (bushel per acre) basis. All data were processed using analysis of variance, PROC GLIMMIX, with SAS v. 9.4 (SAS Institute Inc., Cary, N.C.), and means were separated using a protected least significant difference test ($P = 0.1$).

Results and Discussion

In 2019, on 10-in. row spacings at the RREC on a DeWitt silt loam soil, Diamond yielded at least 26 bu./ac more than when it was planted at all other spacings (Fig. 1) and RT XP753 yielded at least 22 bu./ac more than when it was planted at all other spac-

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

[2] Rice Extension Agronomist, Program Associate, Program Associate, Program Technician, Program Associate, and Program Associate, respectively, Department of Crop, Soil, and Environmental Sciences, Stuttgart.

ings (Fig. 1). When planted at 10-in. row spacing at the NEREC on a Sharkey clay, Diamond yielded at least 16 bu./ac more than when it was planted at 3.25-in. and 15-in. row spacings (Fig. 2) and RT XP753 yielded at least 14 bu./ac more than when it was planted at all other spacings (Fig. 2). Rice grain yield was not influenced by a row spacing × seeding rate interaction, but only the main effect was documented in response to row spacing at each location. It should be noted that due to harvest equipment design, the 10-in. row spacing resulted in an unequal number of non-harvested border rows (1 border row versus 2 border rows) outside of the harvested area compared to the other row spacings which had equal numbers of borders rows outside the harvested area (4 versus 4 for 3.25-in. spacing; 2 versus 2 for 7.5-in. spacing; and 1 versus 1 for 15-in. spacing). This discrepancy will need to be accounted for in future studies.

Practical Applications

The importance of this research suggests increasing to a 10-in. drill row spacing has the potential to increase yield because of the significantly higher yields obtained with the 10-in. row spacings at the RREC and at the NEREC, on a silt loam soil and a clay soil, respectively. This may also be valuable to producers growing rice in heavy clay soils, as the 10-in. drill spacing is less likely to accumulate large clods of soil than a narrower 7.5-in. drill spacing. Additionally, a rice drill row spacing increase to 10 inches may provide a convenience to producers planting in a rice/soybean rotation. Further research is needed to acquire subsequent site-year data to assist producers in making crop management decisions.

Acknowledgments

The authors wish to thank all Arkansas rice growers for financial support through the Rice Check-Off funds administered by the Arkansas Rice Research and Promotion Board as well as the University of Arkansas System Division of Agriculture.

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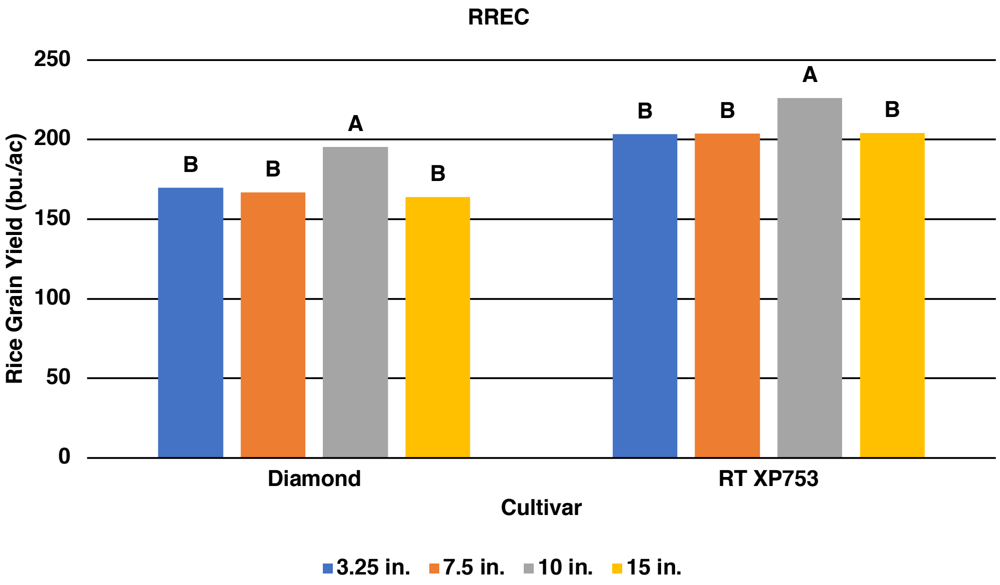

Fig. 1. Assessment of 3.25-, 7.5-, 10-, and 15-in. row spacings planted in Diamond and RT XP753 on rice grain yield for a trial conducted at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC) during 2019. Bars within a cultivar with the same letter are not significantly different ($P < 0.1$).

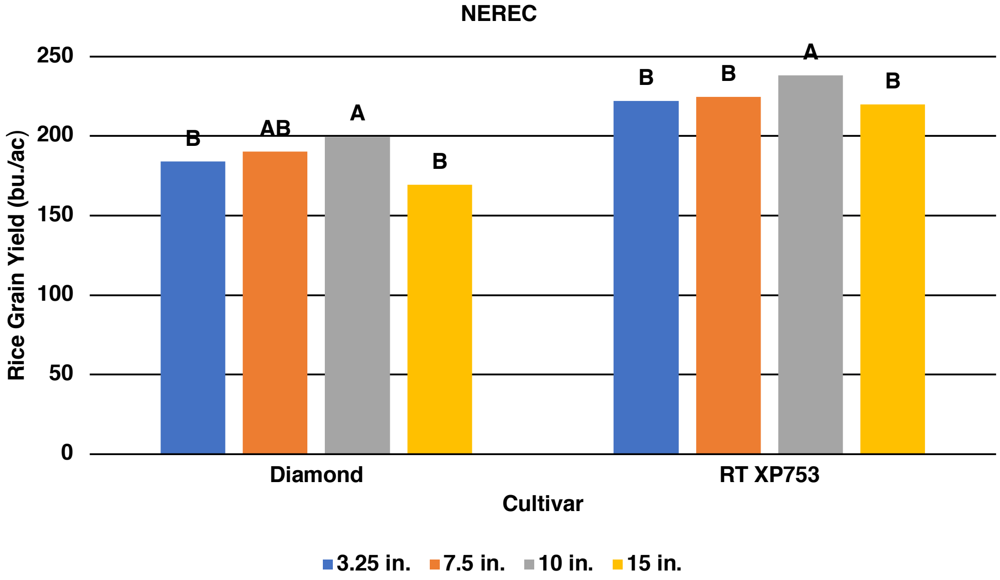

Fig. 2. Assessment of 3.25-, 7.5-, 10-, and 15-in. row spacings planted in Diamond and RT XP753 on rice grain yield for a trial conducted at the University of Arkansas System Division of Agriculture's Northeast Research and Extension Center (NEREC) during 2019. Bars within a cultivar with the same letter are not significantly different (P < 0.1).

Starter Nitrogen Source and Preflood Nitrogen Rate Effects on Rice Grown on Clayey Soils

L.R. Martin,[1] N.A. Slaton,[2] B.R. Golden,[3] T.L. Roberts,[2] and J. Hardke[4]

Abstract

Farmers often apply 'starter' fertilizer-nitrogen (N) shortly after rice (*Oryza sativa* L.) emergence to stimulate seedling growth. The objective of this research was to examine the effects of starter-N source and preflood-N rate on the grain yield of rice grown on clayey-textured soils. Research was conducted at the University of Arkansas System Division of Agriculture's Rohwer Research Station (RRS), Rohwer, Arkansas and the Delta Research and Extension Center (DREC) in Mississippi. Four starter-N sources including no-N (NONE), ammonium sulfate (AMS), diammonium phosphate (DAP), and urea treated with N-(n-butyl) thiophosphoric triamide (UREA) were applied at 21 lb N/ac at the 2-leaf stage in combination with 5 preflood-N rates (0 to 200 lb N/ac) applied to 5-leaf rice. Rice cultivars CL153 and RiceTec Gemini 214 CL (Gemini) were grown at the RRS, and CL153 and RiceTec CLXL745 (CLXL745) were grown at the DREC. Regardless of N source, starter-N increased canopy cover of CL153 and Gemini up to 5 weeks after starter-N was applied by 2% to 87% compared to rice that received no starter-N. The fertilizer-N recovery efficiency of rice receiving no starter-N ranged from 69% to 79% at RRS and 51% to 60% at DREC. At RRS, grain yields of CL153 increased significantly with each increase in preflood-N rate, averaged across starter-N sources, with maximum yields of 174 bu./ac for rice fertilized with 200 lb preflood-N/ac. Gemini grain yields showed an interaction among starter-N source and preflood-N rates where starter-N applications of AMS and UREA tended to increase grain yields compared to no starter-N at suboptimal preflood-N rates. At DREC, CL153 and RT CLXL745 grain yields increased significantly with each increase in preflood-N rate with a maximum yield of 178 bu./ac (CL153) and 237 bu./ac (RT CLXL745) for rice fertilized with 200 lb preflood-N/ac. Based on the 4 trials, starter-N applied as AMS or UREA tended to increase early season canopy closure and grain yield of rice grown on clayey soils, especially for suboptimal preflood-N rates.

Introduction

Starter-N fertilizer applied to upland crops can improve early season vigor and sometimes yield. Applications of starter-N applied at planting has been reported to increase the yields of cotton (*Gossypium hirsutum* L.) (Bednarz et al., 2000) and corn (*Zea mays* L.) to varying levels (Niehues et al., 2004). The benefits of starter-N applied to rice grown in the direct-seeded, delayed-flood system has received less attention than upland crops but is of interest because seedling rice often grows very slowly on clayey soils. Golden et al. (2017) showed that starter-N aided rice recovery from clomazone injury and increased yield compared to clomazone-injured rice that received no starter-N. Satterfield et al. (2018) concluded that 20 lb N/ac as ammonium sulfate applied to 2-leaf rice grown on a clayey soil did not increase plant height or grain yield, but did increase total dry matter and N uptake during 1 out of 2 research years. The objective of this research was to examine whether rice grown on clayey soil will respond positively to starter-N source and, if so, how starter-N may interact with and influence rice yield response to preflood urea-N rate.

Procedures

Field trials were established at the University of Arkansas System Division of Agriculture's Rohwer Research Station (RRS) near Rohwer, Arkansas on soil mapped as a Sharkey/Desha clay and the Mississippi State University's Delta Research and Extension Center (DREC) in Stoneville, Mississippi on a Commerce silty clay. Soybean (*Glycine max* L.) was the previous crop grown, and conventional tillage was implemented at both locations. At the RRS, individual plots measured 6.5 ft wide and 18 ft long, allowing for 9 rows of rice spaced 6 in. apart in the center of the plot area. The rice cultivars at RRS were treated with NipsIt Suite (Valent, Walnut Creek, Calif.) with a rate of 2.9 oz/cwt and AV-1011 bird repellent (Arkion Life Sciences, New Castle, Del.) with a rate of 18.3 oz/cwt and drill-seeded at 78 lb seed/ac for CL153 and 30 lb seed/ac for RT Gemini 214 CL [Gemini] (Table 1). At the DREC, individual plots were 5.5 ft wide and 15 ft long and contained 8 rows spaced 8 in. apart. Rice treated with CruiserMaxx Rice (Syngenta, Greensboro, N.C.) at a rate of 7 oz/cwt was drill seeded at 78 lb seed/ac for CL153 and 30 lb seed/ac for RT CLXL745 [CLXL745] (Table 1). Each experiment contained a total of 20 treatments and 4 replicates arranged in a randomized complete block design. The 20 treatments included 4 starter-N sources, including no starter-N (NONE), ammonium sulfate (AMS), diammonium phosphate (DAP), and N-(n-butyl) thiophosphoric triamide (NBPT)-treated urea (UREA), and 5 preflood-N rates. The starter treatments were applied at the 2-leaf stage at 21 lb N/ac. Preflood-N rates of 0, 50, 100, 150, and 200

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[1] Program Technician, Rohwer Research Station, Rohwer.

[2] Professor, Professor, and Associate Professor, Department of Crop, Soil, and Environmental Sciences, Fayetteville.

[3] Associate Extension Research Professor, Delta Research and Extension Center, Stoneville, Mississippi.

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

lb N/ac were applied at the 5-leaf stage with urea treated with NBPT (Agrotain®) at 0.032 oz/lb urea as the N source. Following the preflood urea application to dry soil, rice was flooded within 1 to 2 days (Table 1).

The Canopeo application (Oklahoma State University) was utilized to measure canopy coverage for both cultivars at the RRS. A tripod-mounted iPad was used to take pictures 3 ft above the soil surface in each plot. Canopy cover was first measured immediately before starter-N was applied and continued every 7 days for 5 weeks until canopy cover reached ~100%.

At early heading (~R3), plant samples were collected from a 6-ft section of 1 inside drill-row of each plot of CL153 at the RRS and the DREC (Table 1). Plant samples were oven-dried, weighed for total dry matter (lb/ac), and a subsample was used to determine the total-N concentration of plant tissue by combustion (elementar rapid N III, Elementar Analysensysteme GmbH, Hanau, Germany; Campbell, 1992). The aboveground-N content (lb N/ac) was calculated as the product of N content and dry matter at the R3 growth stage. Fertilizer-N recovery efficiency was calculated by the difference method, which involves subtracting the N content of rice that received no starter or preflood-N from the N content of each treatment receiving fertilizer-N. The entire plot of rice was harvested with a small plot combine and grain weight was adjusted to a uniform moisture content of 12% for calculating grain yield.

Each experiment (unique cultivar/site combination) was a randomized complete block design with a 4 (starter-N source) by 5 (preflood-N rate) factorial structure that included 4 blocks. Analysis of variance was performed by site and cultivar using the GLM procedure of SAS v. 9.4 (SAS Institute, Inc., Cary, N.C.) with significant differences defined at the 0.05 level.

Results and Discussion

At the RRS, starter-N, regardless of the source, increased canopy cover by 2% to 87% compared to rice that received no starter-N, averaged across preflood-N rates. Canopy cover of CL153 and Gemini receiving starter-N from AMS, DAP, and UREA increased for 5 weeks after starter-N application compared to no starter-N when averaged across preflood-N rates (Table 2). Starting at 3 weeks after starter-N application (WAS; 1 week after preflood-N application), CL153 showed a consistently significant difference when applying UREA starter-N, producing greater canopy coverage than DAP but not compared with AMS. Canopy coverage of Gemini receiving starter-N source was always greater than that of Gemini receiving NONE, but the differences among starter-N sources were small or not significant. These results show that 21 lb N/ac applied as starter-N at the 2-leaf stage increased early season rice canopy growth compared with rice that received no starter-N. Benefits from the increase in early canopy growth could help reduce weed pressure, defer rice water weevils due to shorter open water intervals, and allow for quicker permanent flooding.

The aboveground N content at the early heading stage for CL153 at both locations was significantly affected only by the preflood-N rate ($P < 0.0001$). Rice receiving no preflood-N, averaged across starter-N sources, contained 39 lb N/ac (RRS) and 42 lb N/ac (DREC) at early heading (~R3 stage). Nitrogen uptake by CL153 rice at the RRS increased with each increase in preflood-N rate, averaged across starter-N sources [78, 122, 153, and 170 lb N/ac for rice receiving 50, 100, 150, and 200 lb preflood-N/ac, respectively; LSD (0.05) = 15 lb N/ac], but starter-N source averaged across preflood-N rates did not affect N content. Nitrogen uptake for CL153 grown at the DREC also increased with increasing preflood-N rate, averaged across starter-N sources [67, 102, 130, and 162 lb N/ac for rice fertilized with 50, 100, 150, and 200 lb preflood-N/ac, respectively; LSD (0.05) = 21 lb N/ac], but starter-N source did not affect aboveground-N content when averaged across preflood-N rates. The fertilizer-N recovery efficiency of rice receiving no starter-N and preflood-N rates of 50 to 200 lb N/ac ranged from 77% to 87% for RRS and 59% to 72% for DREC.

The interaction between the starter-N source and preflood-N rate was not significant at the RRS for CL153 ($P = 0.2098$) or at the DREC for CL153 ($P = 0.7908$) and RT CLXL745 ($P = 0.1479$) grain yields. However, an interaction did occur with Gemini ($P = 0.0214$) at the RRS (Table 3). The interaction suggested that within the preflood-N rates of 0, 50, 100, and 150 lb N/ac, rice receiving no starter sometimes yielded less than rice receiving starter-N as AMS and UREA but not DAP. The benefit of starter-N tended to diminish as the preflood-N rate increased.

The grain yields of CL153 (RRS), CL153 (DREC), and RT CLXL745 were significantly affected ($P < 0.0001$) by preflood-N rate, averaged across starter-N sources (Table 4). Application of 150 or 200 lb preflood-N/ac maximized yields in all four trials. Norman et al. (2018) conducted a similar study in Arkansas on a Sharkey clay to examine variable preflood-N rates with reports of no significant yield differences between preflood-N rates of 150, 180, and 210 lb N/ac for CL153.

Starter-N source averaged across preflood-N rates did not affect grain yields for CL153 at the RRS, but the starter-N source did significantly influence the grain yield of Gemini at the RRS, as well as CL153 and RT CLXL745 at the DREC (Table 5). Regardless of the trial, rice receiving no starter-N produced the lowest numerical yield among starter-N sources. The yield of rice receiving no starter-N was lower than rice fertilized with AMS and UREA for RT CLXL745 and CL153 at the DREC. At the RRS, Gemini receiving no starter-N produced lower yields than rice receiving starter-N as AMS, DAP, and UREA.

Practical Applications

In 2019, results suggest that starter-N source was beneficial (6 to 12 bu./ac across N rates) to rice yield at 3 of the 4 trials with UREA and AMS providing the most consistent benefits. Starter-N clearly promoted early season growth with the effect lasting for at least 4 weeks following starter-N application, which included 2 weeks after flooding. The hybrid cultivar Gemini at the RRS showed an interaction among starter-N sources and preflood-N rates, where starter-N did benefit grain yields when suboptimal preflood-N was applied, but the benefit diminished when optimal preflood-N was applied. The early season starter-N benefit could be related to the low seeding rate used for hybrid rice and may aid in competition with aquatic weeds.

Acknowledgments

The research was funded by the Rice Check-Off Program, Fertilizer Tonnage Fees, and the University of Arkansas System Division of Agriculture. Special thanks to RiceTec, Inc. for donating the hybrid rice seed, the staff at the Rohwer Research Station and the Delta Research and Extension Center for helping and allowing the rice research to be conducted at their stations, and the staff at the Fayetteville Agricultural Diagnostic Laboratory for the analysis of plant samples.

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Table 1. Dates of selected agronomic management events for three starter-N trials established at the University of Arkansas System Division of Agriculture's Rohwer Research Station (RRS) in Rohwer, Arkansas and Delta Research and Extension Center (DREC) in Stoneville, Mississippi.

Location	Cultivar	Seeding Rate	Planting Date	Starter-N Applied	Preflood-N Applied	Flood Established	Sample Date
		(lb/ac)	---------------------	---------------------	(Month/Day)	---------------------	---------------------
RRS	CL153	78	April 30	May 28	June 12	June 13	July 31
RRS	RT Gemini 214 CL	30	April 30	May 28	June 12	June 13	N/A
DREC	CL153	78	May 29	June 7	July 3	July 3	Aug 13
DREC	RT CLXL745	30	May 29	June 7	July 3	July 3	N/A

Table 2. Analysis of variance for five weeks following starter-N applications (WAS) for canopy cover of CL153 and RT Gemini 214 CL rice cultivars, averaged across preflood-N rates, as affected by the starter-N sources at the University of Arkansas System Division of Agriculture's Rohwer Research Station (RRS) in Rohwer, Arkansas in 2019.

	CL153					RT Gemini 214 CL				
Starter-N Source[a]	1 WAS	2 WAS	3 WAS	4 WAS	5 WAS	1 WAS	2 WAS	3 WAS	4 WAS	5 WAS
	------------	------------	------------	------------	------------	(Canopy Cover %)	------------	------------	------------	------------
AMS	14	29	45	72	85	15	28	43	73	86
DAP	13	30	44	69	84	15	26	42	70	83
UREA	14	33	49	74	87	15	26	43	70	82
NONE	10	21	31	57	82	12	15	27	56	79
P-value	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
$LSD_{0.05}$	1	4	5	4	2	1	3	4	6	2

[a] Ammonium sulfate (AMS); diammonium phosphate (DAP); urea treated with N-(n-butyl) thiophosphoric triamide (UREA); no starter-N (NONE).

Table 3. Grain yields of RT Gemini 214 CL rice cultivar, interaction among starter-N sources and preflood-N rates at the University of Arkansas System Division of Agriculture's Rohwer Research Station (RRS) in Rohwer, Arkansas in 2019.

	Starter-N Sources[a]			
Preflood-N Rate	**NONE**	**AMS**	**DAP**	**UREA**
(lb N/ac)	----------(bu./ac)----------			
0	98	113	103	121
50	165	182	179	175
100	218	235	215	231
150	244	257	263	260
200	265	261	268	255
P-value	0.0214[b]			
$LSD_{0.05}$	14			

[a] Ammonium sulfate (AMS); diammonium phosphate (DAP); urea treated with N-(n-butyl) thiophosphoric triamide (UREA); no starter-N (NONE).

[b] The main effect of the starter-N source (0.0025) and preflood-N rates (<0.0001) were also significant.

Table 4. Grain yields of CL153, RT Gemini 214 CL, and RT CLXL745 rice cultivars, averaged across starter-N sources, as affected by the preflood-N rate at the University of Arkansas System Division of Agriculture's Rohwer Research Station (RRS) in Rohwer, Arkansas and Delta Research and Extension Center (DREC) in Stoneville, Mississippi in 2019.

	Grain Yield			
	RRS		DREC	
Preflood-N Rate	**CL153**	**RT Gemini 214 CL**	**CL153**	**RT CLXL745**
(lb N/ac)	----------(bu./ac)----------			
0	90	109	75	119
50	131	175	114	177
100	153	225	156	211
150	165	256	177	231
200	174	262	178	237
P-value	<0.0001	<0.0001[a]	<0.0001	<0.0001
$LSD_{0.05}$	6	7	4	6

[a] The main effect of the starter-N source (0.0025) and the starter-N source (0.0214) by preflood-N rate interaction were also significant.

Table 5. Grain yields of CL153, RT Gemini 214 CL, and RT CLXL745 rice cultivars, averaged across the preflood-N rate, as affected by the starter-N sources at the University of Arkansas System Division of Agriculture's Rohwer Research Station (RRS) in Rohwer, Arkansas and Delta Research and Extension Center (DREC) in Stoneville, Mississippi in 2019.

	Grain Yield			
	RRS		DREC	
Starter-N Sources[a]	**CL153**	**RT Gemini 214 CL**	**CL153**	**RT CLXL745**
	----------(bu./ac)----------			
AMS	144	210	143	199
DAP	144	205	137	194
UREA	146	208	142	197
NONE	140	198	137	190
P-value	0.4312	0.0025[b]	0.0009	0.0071
$LSD_{0.05}$	6	6	4	5

[a] Ammonium sulfate (AMS); diammonium phosphate (DAP); urea treated with N-(n-butyl) thiophosphoric triamide (UREA); no starter-N (NONE).

[b] The main effect of the preflood-N rate (<0.0001) and the starter-N source (0.0214) by preflood-N rate interaction was also significant.

Summary of Nitrogen Soil Test for Rice (N-STaR) Nitrogen Recommendations in Arkansas During 2019

S.M. Williamson,[1] T.L. Roberts,[1] C.L. Scott,[1] K.A. Hoegenauer,[1] and J.B. Shafer[2]

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 Nitrogen Soil Test for Rice (N-STaR) to determine their field-specific N rates. In 2009, Roberts et al. correlated several years of direct steam distillation (DSD) results obtained from 18-in. soil samples to plot-scale N response trials across the state and developed 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 (using a 12-in. soil sample). To summarize the samples submitted to the N-STaR Soil Testing Lab in 2019, samples were categorized by county and soil texture. Samples were received from 61 fields across 16 Arkansas counties. Total samples received were from 8 clay and 53 silt loam fields. The N-STaR N-rate recommendations for these samples were compared to the producer's estimated N rate, the 2019 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. No significant differences were found when N-STaR recommended an increased N rate. Soil texture was a significant factor ($P < 0.0001$) when N-STaR proposed a decrease in the season total N rate when compared to the standard N rate. County was significant ($P < 0.05$) for decreased N rates when compared to the standard and producer's estimated comparisons suggesting that some areas of the state and specific soil series may have higher residual-N not accounted for by other current N-rate recommendation strategies.

Introduction

Nitrogen (N) recommendations for rice in Arkansas were traditionally 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). In hopes of finding a more field-based factor to drive N recommendations, scientists correlated several years of plant-available N estimates from direct steam distillation (DSD) results from 18-in. soil samples, equivalent to rice rooting depth on a silt loam soil (Roberts et al., 2009), 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 DSD results from 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

In an effort to summarize the effect of the N-STaR program in Arkansas, samples submitted to the N-STaR Soil Testing Lab for the 2019 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 2019 Recommended Nitrogen Rates and Distribution for Rice Cultivars in Arkansas found in the 2019 Rice Management Guide (Hardke et al., 2019), or 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 three 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 14 (SAS Institute, Inc., Cary, N.C.) with means separated using Fisher's least significant difference test ($P = 0.05$).

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[1] Program Associate II, Associate Professor, Program Technician II, and Professor, respectively, Department of Crop, Soil, and Environmental Sciences, Fayetteville.

[2] Program Associate II, Pine Tree Research Station, Colt.

Results and Discussion

Twenty farmers across 16 Arkansas counties submitted samples from 61 producer fields; with only 20.0% of the 304 fields sampled in 2013 when the program was initiated and costs were partially subsidized by the state. Lonoke County ranked sixth in planted acres (USDA-FSA, 2020), submitted the largest number of fields, 33. Twenty-five percent of the fields submitted were collected by extension agents and represented Rice Research Verification (RRVP) fields across the state. The average number of fields submitted by client was 3, with only 3 clients submitting more than 2 fields. One consulting group submitted samples from 27 fields, 44.3% of the fields submitted. Eighty percent of the 2019 samples were received after rice had been planted during the typically wetter months of March and April when soil sampling at proper moisture is more problematic with the remainder submitted in May and June. The samples received were from 53 silt loam fields and 8 clay fields (Table 1).

Planted rice acreage across Arkansas did decrease from 1.43 million acres in 2018 to 1.15 million acres in 2019 (USDA-FSA, 2020), however yet another wet spring, the rush to get rice planted, and unfavorable emergence conditions combined with favorable N prices likely decreased the number of samples that would have been submitted for N-STaR analysis. Just as in previous years, sample submission by county in 2019 (Fig. 1) did not reflect the planted acre estimates (USDA-FSA, 2020) with no samples received from Poinsett county, which had the highest planted acreage estimates.

County ($P < 0.01$) and soil texture ($P < 0.0001$) were found to be significant factors in the fields with a decrease in N rate when the N-STaR recommendation was compared to Arkansas' standard N-rate recommendation of 150 lb N/ac for silt loam soils and 180 lb N/ac for clay soils. This suggests 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). County and soil texture were not significant in the fields where an increase in N rate was recommended by N-STaR. However, it should be noted that 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 fields in this comparison, there was a decrease in the N recommendation for 39 fields (63.9% of the 61 fields submitted) with an average decrease of 33.3 lb N/ac. No change in N recommendation was found for 11 fields, while 11 silt loam fields had an increase in N recommendation (18%), with an average increase of 9.5 lb N/ac. N-STaR recommendations continue to be largely dependent on proper sampling depth for the respective soil texture and the farmer's correct soil textural classification of his field.

Thirty-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 28 fields that were compared, there was a decrease in N recommendations for 23 fields (82.1% of the compared fields) with an average decrease of 33.2 lb N/ac (Table 2). No change in N recommendation was found for 2 fields, while 3 fields had an increase in N recommendation (10.7%), with an average increase of 10.0 lb N/ac. County was a significant factor ($P < 0.05$) for fields that suggested a decrease in the producer's estimate to the N-STaR recommendation, but was not significant in the fields that resulted in an increased N rate (Table 2). This was most likely due to the limited number of fields, all silt loam soil texture, that suggested an increased N rate.

When the N-STaR recommendation was compared to the 2019 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. Twenty-seven fields failed to include cultivar on the N-STaR Sample Submission Sheet and were excluded from this comparison. There was a decrease in the N recommendation for 28 fields (82.4% of the 34 fields) with an average decrease of 37.2 lb N/ac (Table 3). No change in N recommendation was found for 6 fields (17%), while 4 silt loam fields had an increase in N recommendation (11.8%), with an average increase of 10.0 lb N/ac. No significant differences were found in either county or soil texture in this comparison.

In all 3 comparisons, N-STaR proposed decreases as much as 90 lb N/ac in some fields. Decreases greater than 30 lb N/ac were proposed in 34%, 52%, and 64% of fields evaluated in the standard, estimated, and cultivar rate comparisons, respectively. Alternatively, the greatest N-STaR recommended-N rate increase in all comparisons was only 15 lb N/ac.

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 save a large fraction of fertilizer costs as fertilizer-N costs rise in the future as well as decrease 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.

Acknowledgments

This research was funded by Arkansas Rice Check-Off funds administered by the Arkansas Rice Research and Promotion Board and the University of Arkansas System Division of Agriculture. Sincere gratitude is extended to the employees of the N-STaR Soil Testing Lab and the hourly personnel who spent many hours conducting the analysis of N-STaR samples.

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Table 1. Distribution and change in nitrogen (N) fertilizer rate compared to the standard recommendation, producer's estimated N rate, and the 2019 Recommended Nitrogen Rates and Distribution for Rice Cultivars in Arkansas based on soil texture.

Soil Texture	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)	
Standard soil texture						
Clay	8	8	58.8	-	-	-
Silt Loam	53	31	26.8	11	9.5	11
Total	61	39	33.3	11	9.5	11
Producer estimate						
Clay	7	7	37.9	-	-	-
Silt Loam	21	16	31.2	4	10.0	1
Total	28	23	33.2	4	10.0	1
Cultivar						
Clay	8	8	58.75	-	-	-
Silt Loam	26	20	31.5	4	10.0	2
Total	34	28	39.3	4	10.0	2

Table 2. Distribution and change in 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	2	2	72.0	-	-	-
Clay	7	6	28.3	1	10.0	-
Craighead	2	1	10.0	-	-	1
Crittenden	1	1	90.0	-	-	-
Greene	2	2	10.0	-	-	-
Jackson	1	1	55.0	-	-	-
Jefferson	1	1	15.0	-	-	-
Lawrence	3	3	33.3	-	-	-
Lincoln	1	1	20.0	-	-	-
Lonoke	2	1	45.0	-	-	1
Monroe	2	2	35.0	-	-	-
Randolph	1	1	15.0	-	-	-
White	1	1	10.0	-	-	-
Woodruff	2	-	-	2	10.0	-
Total	28	23	33.2	3	10.0	2

[a] Thirty-three fields did not list an estimated N rate on their N-STaR Sample Submission Sheet and were excluded from the analysis.

Table 3. Distribution and change in N rate compared to the 2019 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)	
CL153	2	2	45.0	-	-	-
Diamond	13	1	51.0	2	10.0	1
RT 7311 CL	3	3	25.0	-	-	-
RT CLXL745	1	1	55.0	-	-	-
RT CLXP4534	1	1	15.0	-	-	-
RT Gemini 214 CL	4	4	38.8	-	-	-
RT XP753	10	7	28.6	2	10.0	1
Total	34	28	37.2	4	10.0	6

[a] Twenty-seven fields did not list a cultivar on their N-STaR Sample Submission Sheet and were excluded from the analysis.

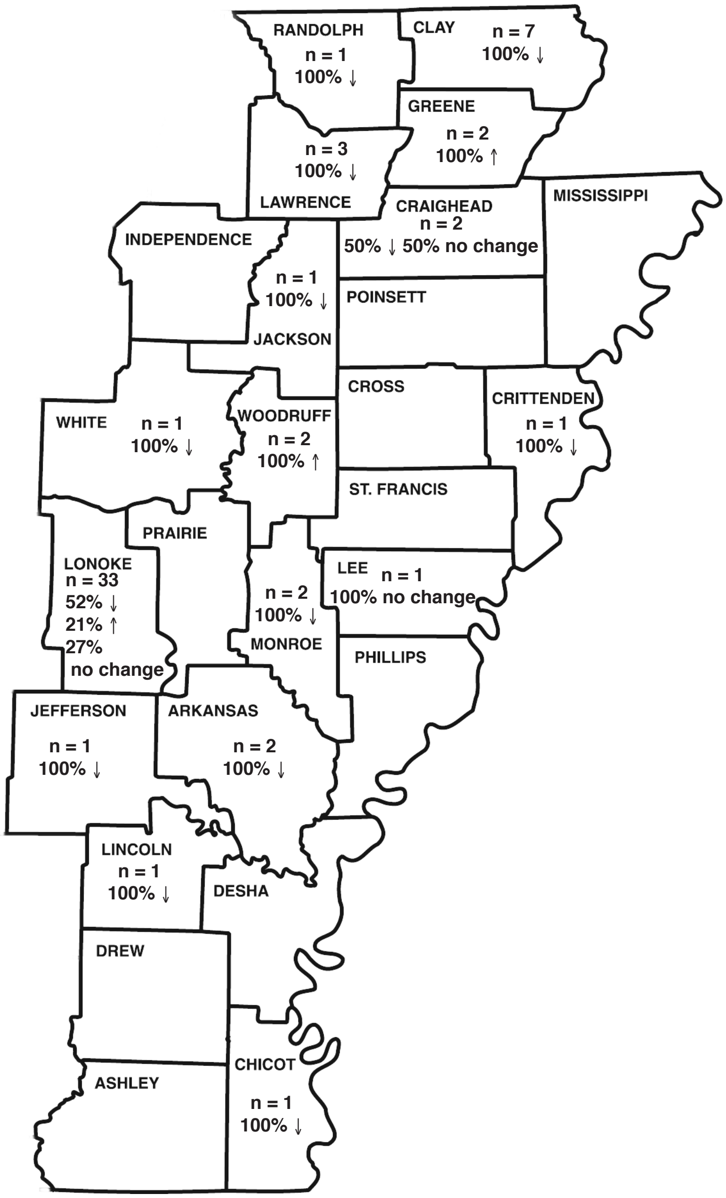

Fig. 1. Number of fields submitted, percent and mean decrease and increase in Nitrogen Soil Test for Rice (N-STaR) N recommendation (lb N/ac) by county compared to the standard recommendation.

Quantifying Physicochemical and Functional Properties of Popular Rice Cultivars in Arkansas for End-Use Applications

S. Graham-Acquaah,[1] T.J. Siebenmorgen,[1] and R.A. January[1]

Abstract

The demand for rice-based food products is increasing with the emerging gluten-free market. The complexity of end-use requirements implies that physicochemical and functional properties of rice, which may vary among cultivars and across growing seasons and environments, must be evaluated regularly to identify cultivars with prospects for various end uses. This study collected rice lots produced under identical soil and environmental conditions to determine differences in the properties of rice cultivars that are produced in Arkansas. Results showed that there are important differences in chalkiness, total lipid and protein contents, as well as peak and setback viscosities, that could be explored for various end uses and breeding objectives.

Introduction

The growth in the gluten-free market is increasing the demand for rice in food product development. Rice is naturally gluten-free and additionally has hypoallergenic properties. Performance of rice in product development depends on flour properties such as water absorption and retention capacity, pasting properties (viscosity of the paste that is formed when flour is mixed with water and heated), and gelatinization temperature. Fundamental research has shown that the aforementioned properties depend on the chemical constituents of rice, mainly starch content. However, there is also evidence suggesting that protein, despite being a minor constituent of rice relative to starch, is additionally vital to processing quality (Derycke et al., 2005a; Patindol et al., 2003; Saleh and Meullenet, 2007). Further, lipid content could impact the behavior of rice flour during processing through the formation of lipid-amylose complexes (Derycke et al., 2005b).

Historically, rice has mostly been consumed as cooked, intact kernels, dictating the emphasis on milling (head rice) yields. The requirement for head rice yield is straightforward—the greater, the better. End-use processing requirements, on the other hand, are more complex and depend on specific end-use products. In order for the rice industry in Arkansas to capitalize on the emerging market for rice-based food products, differences in physicochemical properties of popular cultivars need to be ascertained to identify those that have prospects for specified end uses. Therefore, the goal of this project is to quantify differences in physicochemical and functional properties of popular rice cultivars in Arkansas and relate these properties to end-use processing. This paper reports observed differences in chalkiness, protein content, total lipid content, as well as peak and setback viscosities among cultivars that are produced under identical soil and environmental conditions.

Procedures

Thirty-four rice lots at various harvest moisture contents (HMC) were collected from RiceTec, Inc. show plots at Harrisburg, Arkansas in September 2019. These lots comprised 16 hybrids and 3 pure-line cultivars. Of these, 17 were long-grain and 2 were medium-grain cultivars. With the exception of 4 cultivars, rough rice of each cultivar was collected from replicate plots. The rough rice lots were cleaned using a dockage tester (XT4, Carter-Day, Minneapolis, Minn.), then gently dried to 12.5% moisture content. After drying, duplicate 100-g samples of each cultivar were dehulled using a laboratory sheller (THU 35B-3T, Satake, Tokyo, Japan). Two, 100-kernel subsamples of brown rice kernels were then selected from each dehulled sample and chalk measurements performed on these kernels using an image analysis system (WinSeedle Pro 2005aTM, Regent Instruments Inc., Sainte-Foy, Quebec, Canada). Additional subsamples of approximately 20 g of brown rice were ground to flour. From these brown-rice flour samples, total lipid content was determined using a Soxtec apparatus, and protein content was determined using an automated nitrogen/protein analyzer. To determine paste viscosities of milled rice, 150-g rough rice samples from each lot were first dehulled, then milled for 30 s in a McGill No. 2 laboratory mill; head rice was separated from broken kernels using a shaker table. Afterward, approximately 20 g of head rice from each milled sample was ground to flour and used to determine peak and final viscosities using a viscometer (RVA Super 4, Newport Scientific, Warriewood, Australia). Setback viscosity was calculated as the difference between final and peak viscosities.

Results and Discussion

The rice lots that were evaluated in this study were produced under identical soil and environmental conditions. However, these rice lots, while harvested on the same day, were collected at various harvest moisture contents (HMCs). The effect that HMC could have on rice properties was controlled by including HMC as a factor in a least-squares regression. This provided an adjustment for varying HMCs, thus, permitting the properties of the cultivars to be compared without the influence of HMC. Therefore, differences in physicochemical and functional properties among the cultivars are reasoned to be the result of genotypic differences.

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[1] Graduate Assistant, Distinguished Professor, and Coordinator respectively, University of Arkansas System Division of Agriculture's Rice Processing Program, Department of Food Science, Fayetteville.

Figure 1 shows the protein contents (PCs) of brown rice from the 19 cultivars, sorted from least to greatest PC. Protein content ranged from 8.12% to 9.60%. Diamond, a pure-line cultivar, had the lowest PC while RT 7221 FP, a hybrid, recorded the greatest. Protein restricts the amount of water that rice can absorb and retain during processing (Derycke et al., 2005b). Greater PCs are also usually associated with harder cooked-rice texture (Saleh and Meullenet, 2007).

Figure 2 shows the total lipid contents (TLC) of the 19 cultivars. Total lipid content ranged from 2.02% for RT 7801 to 2.76% for RT V7522 FP. These results lend credence to reports that different cultivars take various durations to mill to the same surface lipid content (SLC); cultivars that have greater TLC are likely to require longer durations to reach the desired SLC after milling (Lanning and Siebenmorgen, 2011).

Figure 3 shows the chalkiness levels of kernels in the various cultivars. A 6.6% percentage point difference existed between the cultivars having the least and greatest chalkiness. Chalky kernels tend to break during milling and thus reduce head rice yields. For milled rice, the presence of chalky kernels degrades its appearance and has a negative impact on consumers' assessment of rice. Additionally, chalky kernels affect the uniformity of cooked rice texture because they tend to have a softer texture than translucent kernels. Although chalkiness has previously been suggested to reduce setback viscosity, a consistent relationship between the chalkiness levels in the cultivars and their setback viscosities was not apparent in this study. A reason for this could be the fact that unlike most previous studies, this study measured chalkiness using brown rice samples. Evaluating chalkiness on brown rice samples is thought to provide a better representation of cultivar differences in chalk levels; chalky kernels that break during milling cannot be quantified for chalk measurement since only head rice samples are used.

Figure 4 shows the peak (Fig. 4a) and setback (Fig. 4b) viscosities of the rice cultivars. The range for peak viscosity is approximately 500 cP versus a range of approximately 1500 cP for setback viscosity. Peak viscosity provides a measure of the extent to which rice flour swells when a slurry of flour is heated. Setback viscosity, on the other hand, measures retrogradation (the tendency of a heated slurry of flour to become viscous when cooled). Common effects of retrogradation are staling of baked products and hardness of cooked rice. The results of this study suggest that should baked products, for instance, be prepared from rice, those that are produced from cultivars that have the least setback viscosities (e.g., Titan, RT 3201 MG, and RT 7521 FP) are likely to be less stale than similar products prepared from cultivars having greater setback viscosities. Additionally, the texture of cooked samples of cultivars with the least setback viscosities is likely to be softer and more sticky than cultivars with greater setback viscosities.

Practical Applications

This study measured the physicochemical and functional properties of selected rice cultivars produced in Arkansas. This information could be useful to rice processors for selecting cultivars based on their end-use requirements. The results also provide insight that can help breeders select parental lines to improve specific traits as regards end-use functionality.

Acknowledgments

The authors acknowledge financial support from the corporate sponsors of the University of Arkansas Rice Processing Program and the Arkansas Rice Checkoff Program, administered by the Arkansas Rice Research and Promotion Board. Support also provided by the University of Arkansas System Division of Agriculture.

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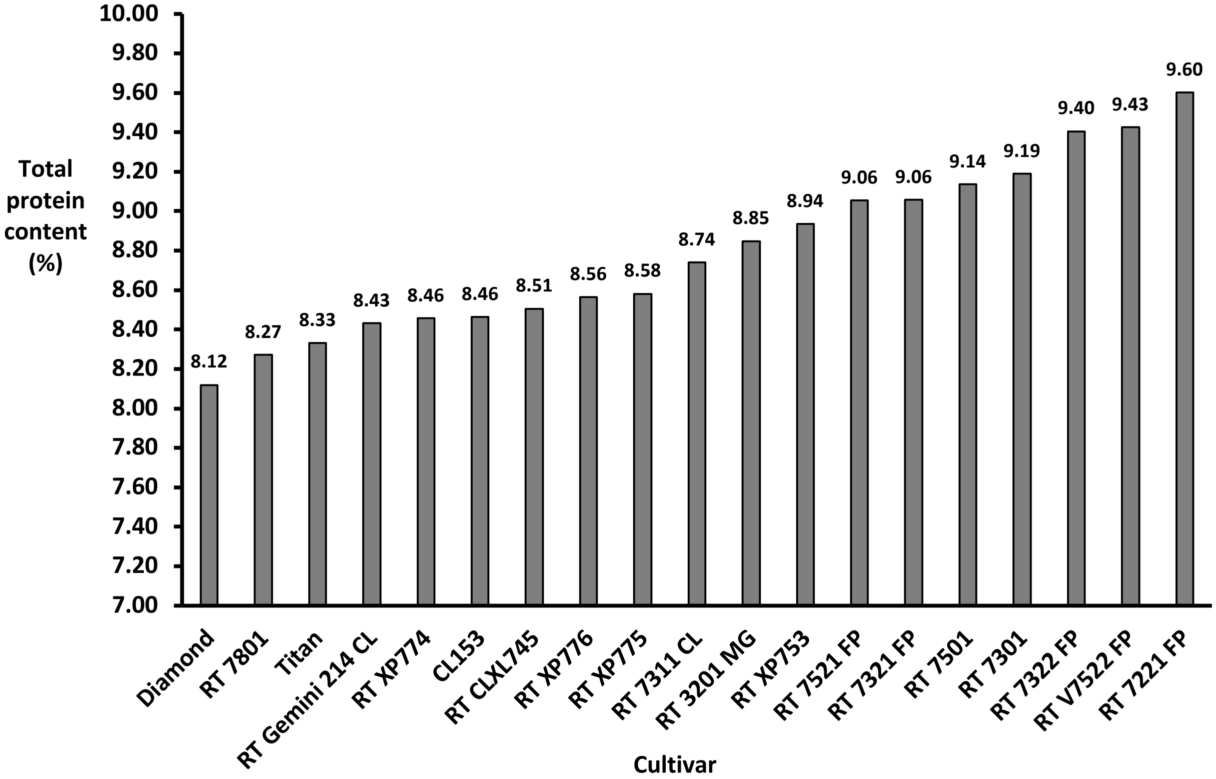

Fig. 1. Protein contents (PCs) of 19 rice cultivars from the 2019 harvest season. Each PC value is the mean of duplicate measurements.

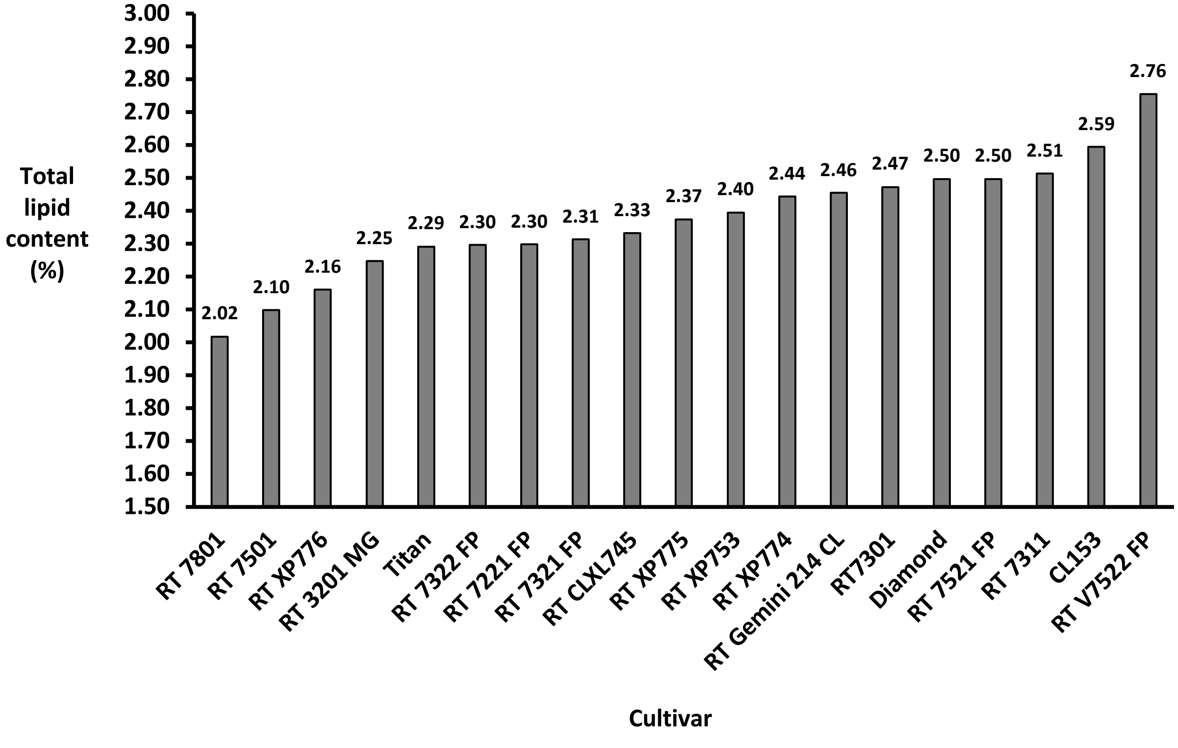

Fig. 2. Total lipid contents (TLCs) of 19 rice cultivars from the 2019 harvest season. Each TLC value is the mean of duplicate measurements.

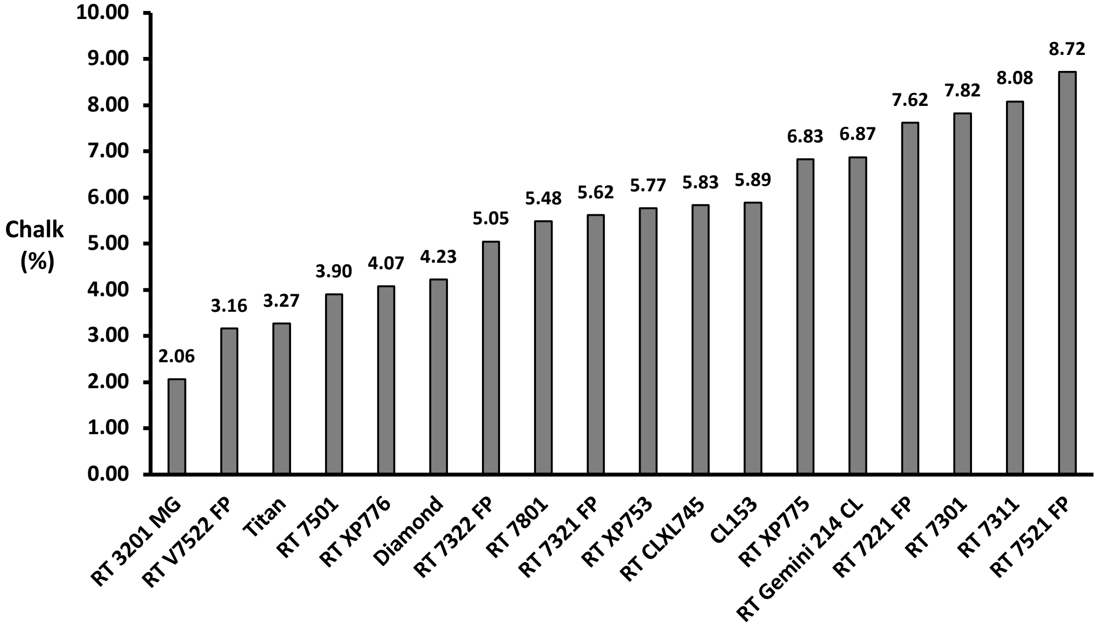

Fig. 3. Chalk levels in brown rice samples of 19 rice cultivars from the 2019 harvest season. Each chalk value is the mean of four measurements.

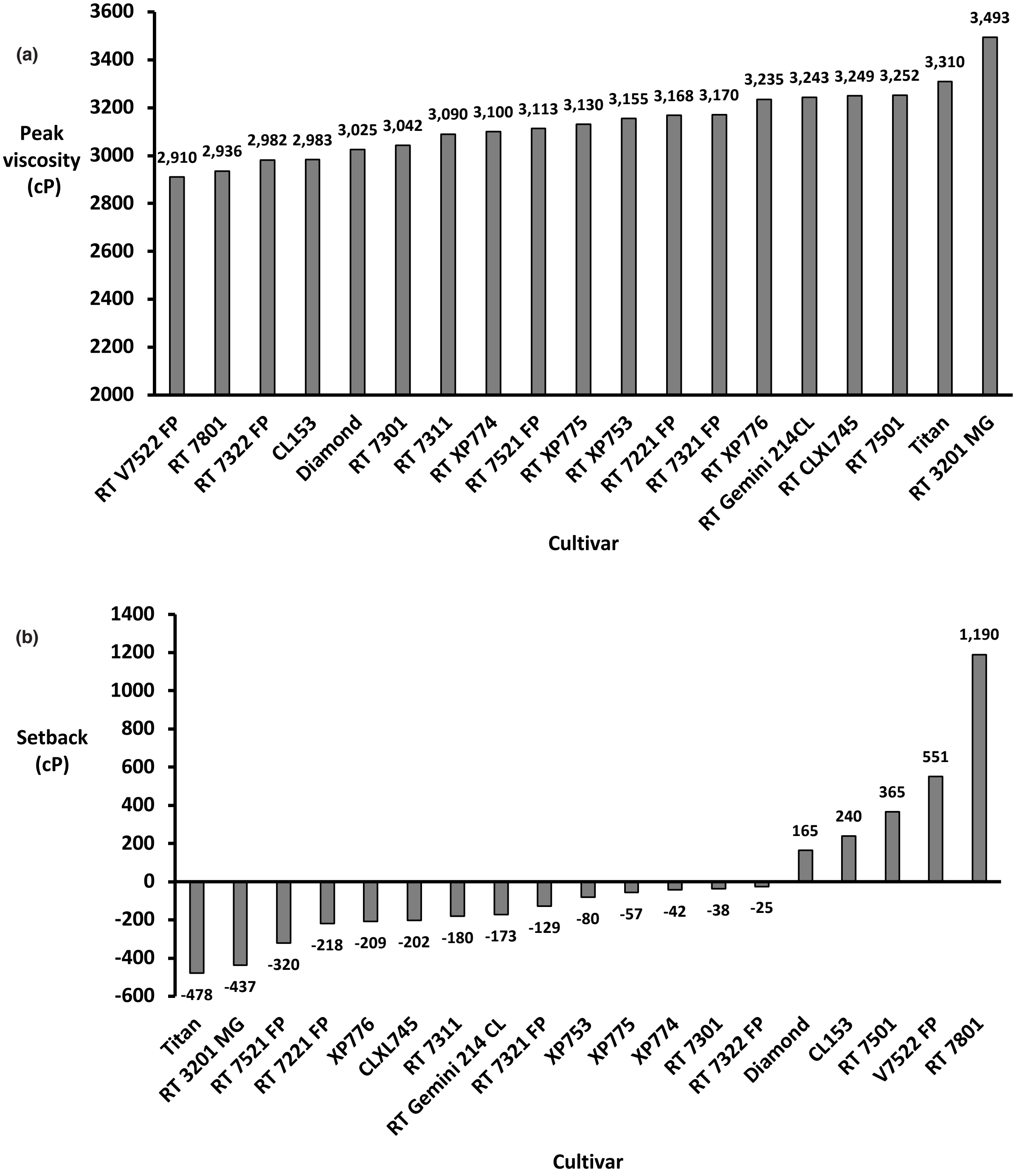

Fig. 4. (a) Peak viscosities and (b) setback viscosities of 19 rice cultivars from the 2019 harvest season. Each value is the mean of four measurements. Setback viscosity represents the difference between final and peak viscosities.

World and U.S. Rice Baseline Outlook, 2019–2029

A. Durand-Morat[1] *and E.C. Chavez*[1]

Abstract

The year 2019 marked a record level of global production and consumption, the second largest level of global rice trade, and the largest stock-to-use ratio since 2001. The global rice market has been dominated by plentiful supplies that have kept international prices soft for the most part. Over the next decade, the average global rice price is projected to increase steadily at 0.77% as global consumption grows faster than global production, causing a decline in the stock-to-use ratio. Global trade is projected to grow by 1.73% annually. India and Thailand maintain their dominant roles in global trade as the top rice exporters, followed by Vietnam, Pakistan, Myanmar, and the United States. China, Nigeria, and the Philippines remain the major global rice importers. The growth in global trade over the next decade is accounted for by expansion in export shipments from India, Thailand, Vietnam, China, and Myanmar; in tandem with strong import demand from countries in Western Africa and the Middle East.

Introduction

After trailing consumption for more than 8 consecutive years, global rice production has outpaced consumption every year since 2008. Global rice production and consumption have grown a cumulative 17% and 13%, respectively, since 2008, leading to the buildup of global rice stocks and curving down the inflationary pressure on rice prices. Asia continues to dominate the global rice market and accounts for 89% of production, 85% of consumption, 93% of stocks, and 82% of the exports worldwide in the last five years.

Rice remains thinly traded, meaning most rice is consumed where it is produced. However, international trade is growing and reached 9.3% of global production in the 2016–2018 period, relative to 7.0% a decade before. India, Thailand, Vietnam, Pakistan, and the U.S. dominate rice exports with a combined share of 76.6% of total world trade in 2016–2018. India's sustained rice production growth in the last decade allowed the country to overtake Thailand as the top global rice exporter in the last several years. However, there has been a growing export competition in the last decade from Myanmar and Cambodia, which are projected to continue making inroads in the coming decade.

Prices in the global rice market have remained soft in 2019. With the exception of Thailand, Asian long-grain rice prices in 2019 have remained low and very competitive relative to rice from other origins. To illustrate, the export price (FOB) for Vietnam's long-grain 5% broken averaged $354 per metric ton (mt), relative to $406 per mt for Thai 100%B, and $541 per mt for U.S. long-grain #2 4% (Fig. 1). The strength of Thai rice export prices vis-à-vis other Asian origins was striking, unsupported by current market conditions, and led to a sharp decline of Thai exports in 2019.

There are a number of recent significant developments in the global rice market that can be considered as the likely main drivers of rice prices, supply, and demand going forward. For instance, the current lack of competitiveness of Thai rice resulting from a strong currency and a production shortfall in 2019 due to adverse weather conditions that included insufficient irrigation water supplies, droughts, and floods in different parts of the country. Another major development is the rise of China as a major rice exporter, reportedly taking advantage of competitive export prices and growing market opportunities in Africa. The country reduced its rice imports by 2.8 mmt in 2018, as demand for foreign supplies decreased, and decided to hold auctions of its old rice reserves. Reports indicate that auction prices were attractive to domestic buyers, and sales have been active, reaching 12 mmt of rice from its state-owned inventories (USDA-FAS, 2019a). Finally, another relevant development is the change in trade policies adopted by the Philippines in 2019, which calls for converting quantitative restrictions on rice imports into tariffs (USDA-FAS, 2019b). The preliminary import figures for 2019 show a sharp increase in rice imports by the Philippines.

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, Arkansas. The model covers 70 countries and regions that produce and consume rice; and generates rice supply and demand as well as international and domestic rice prices.

Most of the details, theoretical structure and general equations of AGRM, with the exception of countries estimated later, can be found in the online documentation by Wailes and Chavez

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[1] Assistant Professor and Program Associate, respectively, Department of Agricultural Economics and Agribusiness, Fayetteville.

(2011). The historical rice data comes from USDA-FAS (2020a, 2020b) and USDA-ERS (2020). Macroeconomic data (e.g., gross domestic product, exchange rate, and population growth) comes from IHS Markit provided by the Food and Agricultural Policy Research Institute (FAPRI)-Missouri. The baseline projections are grounded in a series of assumptions as of January 2020 about the general economy, agricultural policies, weather, and technological change. The basic assumptions include the following: continuation of existing policies; current macro-economic variables; no new WTO trade reforms; and average normal weather conditions.

Results and Discussion[2]

Over the next decade, the average global long-grain rice price is projected to increase steadily by 0.77% annually, as total global net trade grows at 1.73% over the same period. On average, the long-grain rice international reference price, represented by the Thai 100% B FOB, increases from $404 per mt (2016–2018 average) to $439 per mt in 2029. Over the same period, the average international price for medium-grain rice is projected to remain high ranging from $782 per mt (2016–2018 average) to $843 per mt in 2029 (Table 1), as export supplies continue to be limited by water-related production constraints in Australia and Egypt which are traditional medium-grain suppliers. Egypt has a water-related policy of restricting rice planted area with penalties for policy-breakers, but there are indications that local rice farmers continue to plant rice as evidenced by the historical data on planted area (USDA-FAS, 2020b). Depending on how this plays out in the future, this situation could potentially present market opportunities for U.S. medium-grain rice producers.

Western Hemisphere long-grain prices, represented by the U.S. No. 2–4% FOB Gulf price, remain substantially higher than Asian long-grain rice prices. The average U.S. price margin, estimated as the difference between U.S. No. 2–4% and the Thailand 100% B price, which is considered the long-grain international rice reference price, over the last decade (2010–2019) was $93 per mt, with values reaching as high as $181 per mt in 2017 and $167 in 2018. Over the next decade, the margin is projected to average $149 per mt, with values increasing from $143 per mt (2016–2018 average) to $160 per mt in 2022 before narrowing steadily thereafter, reaching $122 per mt by 2029 (Table 1 and Fig. 2). This is consistent with the expected impact of the increasing inroads of Asian rice, particularly from Vietnam, into the Latin American markets. However, the convergence of the two prices is not likely since U.S. rice exports benefit greatly from preferential access in its core rice markets (e.g., Mexico, Central America, and Colombia).

Over the next decade, India and China will remain the major players in the global rice economy given the sheer magnitude of their rice sectors. These two countries will have an average combined global share of 44.9% of total area harvested, 51.0% of total production, 48.6% of total consumption, 23.6% of total net trade, and 80.7% of total stocks. On average, the two countries combined are projected to account for 35.9% of the world population over the same period.

Global rice output is projected to continue expanding over the next decade, driven by the use of higher-yielding varieties and hybrids and other improved production technologies—in line with more focused self-sufficiency programs of the major consuming countries. World rice production expands by nearly 27.8 mmt over the next decade, equivalent to an annual growth of 0.5%, reaching 522.8 mmt in 2029. (Table 2). World rice harvested area is down slightly over the same period as the expected substantial area declines in China (-1.94 million hectares) and Vietnam (-445 thousand hectares) overshadow the combined area expansion in other countries.

By volume, about 29% of the expected net growth in global rice output over the next decade will come from India, and nearly 55% from 7 countries that include Bangladesh, Indonesia, Thailand, Myanmar, Vietnam, Cambodia, and the Philippines. In contrast, rice production in China is projected to decline by 6.9 mmt, followed by minor production losses in other countries such as Brazil, Japan, and South Korea. In contrast, total U.S. rice production is projected to increase by a total of 215 thousand metric tons (tmt) over the same period, equivalent to an average annual growth of 0.3% (Table 3).

Over the next decade, world rice consumption will continue to be driven by population growth as global average per-capita rice consumption declines. 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. Demographic trends also weaken rice demand, as aging populations and increased health-consciousness cause a shift in preferences away from carbohydrates and towards protein-based diets. Over the same period, global rice consumption is projected to increase by 47 mmt, reaching nearly 529 mmt in 2029, which is equivalent to an annual growth of 0.85%. This growth in global demand is due solely to population growth, as the average per-capita use of rice is projected to decline by 0.2% a year (Table 2).

About 20% of the net growth in global rice consumption is accounted for by India; 18% by the three countries of Bangladesh, the Philippines, and Indonesia combined; and 23% by the Economic Community of West African States (ECOWAS[3]). The U.S. rice total consumption increases by 64 tmt over the same period, reaching 4.4 mmt in 2029 or an annual growth of 0.13%, which comes solely from population growth as per capita use declines by 0.6% per year.

We project that total global rice trade will expand by 9.6 mmt or a growth of 1.73% annually over the next 10 years, reaching 55.8 mmt in 2029 compared to 46.2 mmt for the period 2016–2018 (Table 1). On the exporters' side, the significant investment in production and processing capacity in the Mekong Delta in Vietnam, Cambodia, and Myanmar bodes well for these countries' increasing role as important global rice suppliers over the same period. As low-cost producers, these countries are well-poised geographically to supply the Chinese rice market.

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[2] 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.

[3] Benin, Burkina Faso, Cape Verde, Cote d'Ivoire, Gambia, Ghana, Guinea, Guinea-Bissau, Liberia, Mali, Niger, Nigeria, Senegal, Sierra Leone, and Togo.

The productivity gains from hybrids and Global Rice Science Partnership (GRiSP) research are also expected to have positive impacts on Asian and African rice economies over the next decade.

While Thailand has experienced some challenges recently from competition and some water- and weather-related issues, the country is projected to recover over the next decade and maintain its strong presence in the international rice market given its good infrastructural resources and concerted focus on developing branded high-quality rice. However, the country is not expected to regain the top spot in the international market. India is expected to remain the leading rice exporter owing to its steady and impressive production growth.

For the U.S., total exports over the next decade are expected to increase by 208 tmt, reaching 3.3 mmt in 2029; and imports will gain 62 tmt, totaling 908 tmt in 2029. For reference purposes, detailed U.S. rice supply and use data are presented in English units and in paddy basis (rough rice equivalent) in Table 3.

Over the same period, Myanmar and Cambodia are both expected to assume increasing roles as global rice suppliers. Myanmar's exports are projected to expand from 2.87 mmt (2016–2018 average) to 3.81 mmt in 2029, supported by yield-based growth in production. Cambodia's exports, on the other hand, are projected to grow at 4.8% per year, reaching 2.12 mmt in 2029 from 1.27 mmt average in 2016–2018, as both area and yield growth cause production to exceed consumption consistently.

On the import side, China, Nigeria, and the Philippines are expected to be the leading rice importers over the next decade. China will remain an important major rice importer, although its imports have substantially gone down recently as the country held auctions to dispose of some of its old stock reserves. In February 2019, the World Trade Organization ruled in favor of a 2016 U.S. complaint that China has consistently exceeded its WTO agricultural subsidy limits. This ruling can have significant implications for the Chinese and global rice markets, including China's rice imports, in the coming years.

China has slowly opened market access to India, Japan, and recently the United States for milled rice. Currently, some countries have bilateral phytosanitary protocols on milled rice with China, including Cambodia, India (both Basmati and Non-Basmati) Japan, Laos, Myanmar, Pakistan, Thailand, Uruguay, Vietnam, Taiwan, and the United States (USDA-FAS, 2019c).

In general, expansion in imports is associated with a combination of relatively fast population growth and lagging production relative to consumption. An example is Nigeria with imports expanding at 5.0% per year, driven by the 2.8% population-led growth in consumption that exceeds the 1.8% growth in output. The rest of Western Africa and the Middle East show strong expansion in import demand.

Global rice stocks are projected to tighten slightly over the next decade, with the stocks-to-use ratio projected to decline from about 0.26 in 2018 to 0.24 in 2029, reflecting the relatively faster growth in total global rice consumption relative to the gains in total global rice output. Global rice stocks will have a net increase of 3.0 mmt over the same period, with an 8.0 mmt combined increase in stocks of India, Vietnam, and Myanmar partly offset by a decline of 4.0 mmt in China as the latter reduces imports and disposes of old rice reserves.

Practical Applications

Understanding the market and policy forces that drive the global rice market are beneficial for Arkansas rice producers and other stakeholders. This is especially true because Arkansas is the top rice-producing state in the U.S., accounting for nearly 42% of the country's rice output (2016–2018 average), and about half of Arkansas' annual rice crop is exported. Market prices received by Arkansas rice producers are primarily determined by the dynamics that play out in the international rice trade. While the results presented in this outlook are not predictions, they can be considered as a synthesis of the combined impacts of these factors, and indicative of what could happen over the next decade. They could serve as a baseline reference for further analysis. The estimates are intended for use by government agencies and officials, farmers, consumers, agribusinesses, and other stakeholders that conduct medium- and long-term planning that may include a rice component in their work.

Acknowledgments

This material is based upon work supported in part with funding provided by the rice producers of Arkansas through the rice check-off funds administered by the Arkansas Rice Research and Promotion Board. The authors wish to thank the University of Arkansas System Division of Agriculture for its support; as well as the Arkansas rice farmers who provided support through the Rice Research and Promotion Board, which provided part of the funding for the annual development, update, and maintenance of the Arkansas Global Rice Model. The model was updated three times in 2019 and once in February 2020 in collaboration with FAPRI-Missouri, which provided the major portion of the funds for the global rice modeling program of AGREP.

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Table 1. Projected changes in world rice total trade by country (in 1000 metric tons) with U.S. and global prices.

Country	2016-2018 Average	2029	Change	Country	2016-2018 Average	2029	Change
			Exporters				
India	11,417	13,990	2573	EU 28	329	392	63
Thailand	10,190	12,278	2087	Australia	189	288	99
Vietnam	6643	8022	1379	Peru	97	89	-8
Pakistan	4020	3845	-175	Guinea	87	100	13
United States	3127	3334	208	Cote d'Ivoire	83	100	17
Myanmar	2867	3805	939	Egypt	57	100	43
China	1664	2678	1014	Japan	57	65	8
Cambodia	1267	2117	851	Turkey	43	25	-18
Brazil	927	759	-168	Tanzania	33	30	-3
Uruguay	830	907	77	Venezuela	20	0	-20
Paraguay	632	905	273	Senegal	10	10	0
Guyana	433	828	394	Sri Lanka	5	5	0
Argentina	380	344	-36	Laos	-111	89	200
				Rest of world	923	696	-227
Total Exports					**46,218**	**55,801**	**9583**
Importers							
China	4500	3853	-647	Canada	378	467	89
Nigeria	2133	3662	1529	Sierra Leone	373	414	41
ECOWAS 7[a]	2107	3868	1762	Egypt	363	200	-163
Philippines	1990	3115	1125	Liberia	343	483	139
EU 28	1982	2217	234	Sri Lanka	339	-23	-362
Cote d'Ivoire	1340	2326	986	Hong Kong	335	417	82
Saudi Arabia	1278	1737	458	Peru	324	260	-64
Iran	1267	1672	405	Singapore	313	337	23
Bangladesh	1225	516	-709	Turkey	273	193	-81
Iraq	1133	1325	191	Tanzania	267	1043	776
Senegal	1117	1889	773	Thailand	250	250	0
South Africa	1030	1206	176	Mali	243	904	660
Indonesia	1000	1229	229	Australia	188	165	-23
Malaysia	900	860	-40	Chile	161	197	36
United States	846	908	62	Costa Rica	153	176	22
Mexico	814	952	138	Colombia	145	197	52
Ghana	760	1296	536	Honduras	129	235	105
Guinea	703	818	115	Uganda	117	289	172
Japan	693	682	-11	Taiwan	114	126	12
Brazil	692	1437	745	Guatemala	95	136	41
Kenya	692	1353	661	Nicaragua	89	88	-1
Mozambique	662	1089	427	Panama	85	119	34
Cameroon	625	946	321	Brunei	42	59	16
Cuba	503	586	83	Rwanda	40	55	15
Haiti	478	575	97	Dominican Rep.	30	57	27
Vietnam	467	400	-67	Malawi	15	53	38
Venezuela	432	637	205	Zambia	10	25	15
South Korea	406	409	2	Pakistan	3	0	-3
Madagascar	402	673	271	Paraguay	2	2	0
				Rest of world	8817	6645	-2172
Total Imports					**46,218**	**55,801**	**9583**
			Prices (US$/metric ton)				
Long-grain International Rice Reference Price (Thailand 100% B)					404	439	35
U.S. No. 2 long-grain FOB[b] Gulf Ports					547	561	15
U.S. No. 1 medium-grain FOB California					782	843	61

[a] 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 1000 metric tons) and macroeconomic data.

Variable	2016-2018 Average	2029	Change
Area Harvested	162,912	162,504	(408)
Yield (kg/ha)	3038	3217	179
Production	494,985	522,820	27,836
Beginning Stocks	151,669	168,556	16,887
Domestic Supply	646,653	691,3762	44,723
Consumption	481,774	528,836	47,062
Ending Stocks	162,323	165,641	3318
Domestic Use	644,098	694,477	50,380
Total Trade	46,218	55,801	9583
Stocks-to-Use Ratio	25.2%	23.9%	-1.3%
Annual population growth	1.11%	0.84%	-0.27%
Annual real GDP[a] growth	3.11%	2.85%	-0.26%

[a] GDP = Gross domestic product.

Table 3. U.S. rice supply and utilization (in paddy basis, million hundredweight unless specified otherwise), prices, and macro data.

Variable	2016-2018 Average	2029	Change
Yield (lb/ac, paddy basis)	7482.8	8326.2	843.5
Total Harvested Area (million ac)	2793.7	2588.3	-205.3
Supply	276.1	281.5	5.4
Production	208.8	215.5	6.7
Beginning Stocks	40.6	37.4	-3.2
Imports	26.7	28.6	1.9
Domestic Use	137.4	139.5	2.0
Food	111.4	127.7	16.3
Seed	2.1	2.0	-0.1
Brewing	19.1	20.3	1.2
Residual	4.9	-10.5	-15.4
Exports	98.4	105.0	6.6
Total Use	235.9	244.5	8.6
Ending Stocks	40.1	37.0	-3.1
Stocks-to-Use Ratio	16.9%	15.1%	-1.8
Market Prices (US$/cwt)			
Loan Rate	6.50	7.00	0.50
Season Ave. Farm Price	11.87	12.93	1.07
Long-Grain Farm Price	10.64	12.04	1.40
Medium-Grain Farm Price	15.90	15.96	0.06
Japonica Farm Price	18.07	17.80	-0.27
Southern Medium-Grain Farm Price	11.37	12.46	1.10
Reference Prices (US$/cwt)			
Long-Grain Farm Price	14.00	14.00	0.00
Southern Medium-Grain Farm Price	14.00	14.00	0.00
Japonica	16.10	16.10	0.00
Long-Grain Export Price, FOB* Houston (U.S. No. 2)	24.80	25.46	0.66
Medium-Grain Price, FOB[a] CA (U.S. No. 2)	35.46	38.22	2.77
Average World Price (US$/cwt)	8.92	10.44	1.52
Income Factors (Million U.S. Dollars)			
Production Market Value	2505	2816	311
Program Payment	606	371	-235
Total Income	3111	3187	76
Market Returns Above Variable Cost (US$/ac)	365	273	-92
Total Returns Above Variable Cost (US$/ac)	579	416	-163
Per Capita Use (lb/capita)	42.2	39.6	-2.6
Population growth (%)	0.66	0.61	-0.05
Real GDP Growth (%)	2.31	2.15	-0.16

[a] FOB = Free On Board.

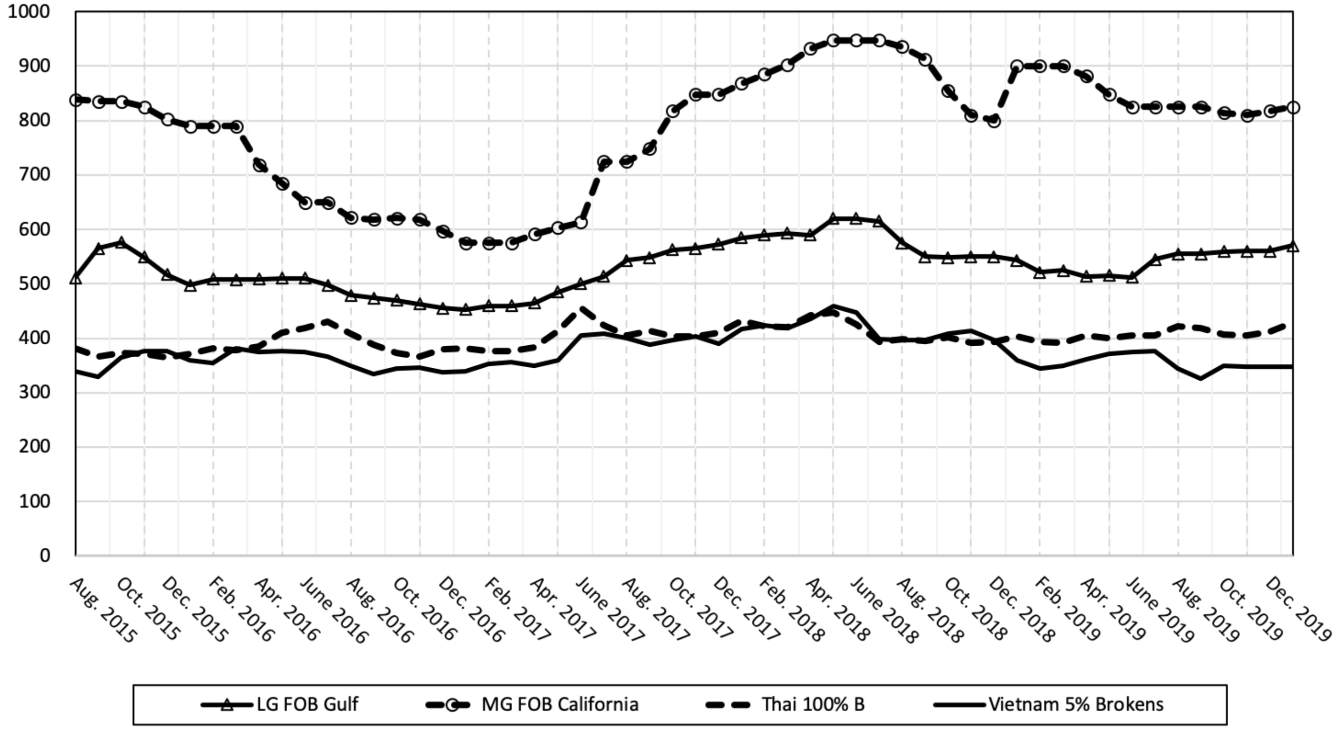

Fig. 1. Monthly Historical U.S. and Asian milled rice prices, US$ per metric ton, August 2015-January 2020. Source: USDA-ERS Rice Outlook, January 2020.

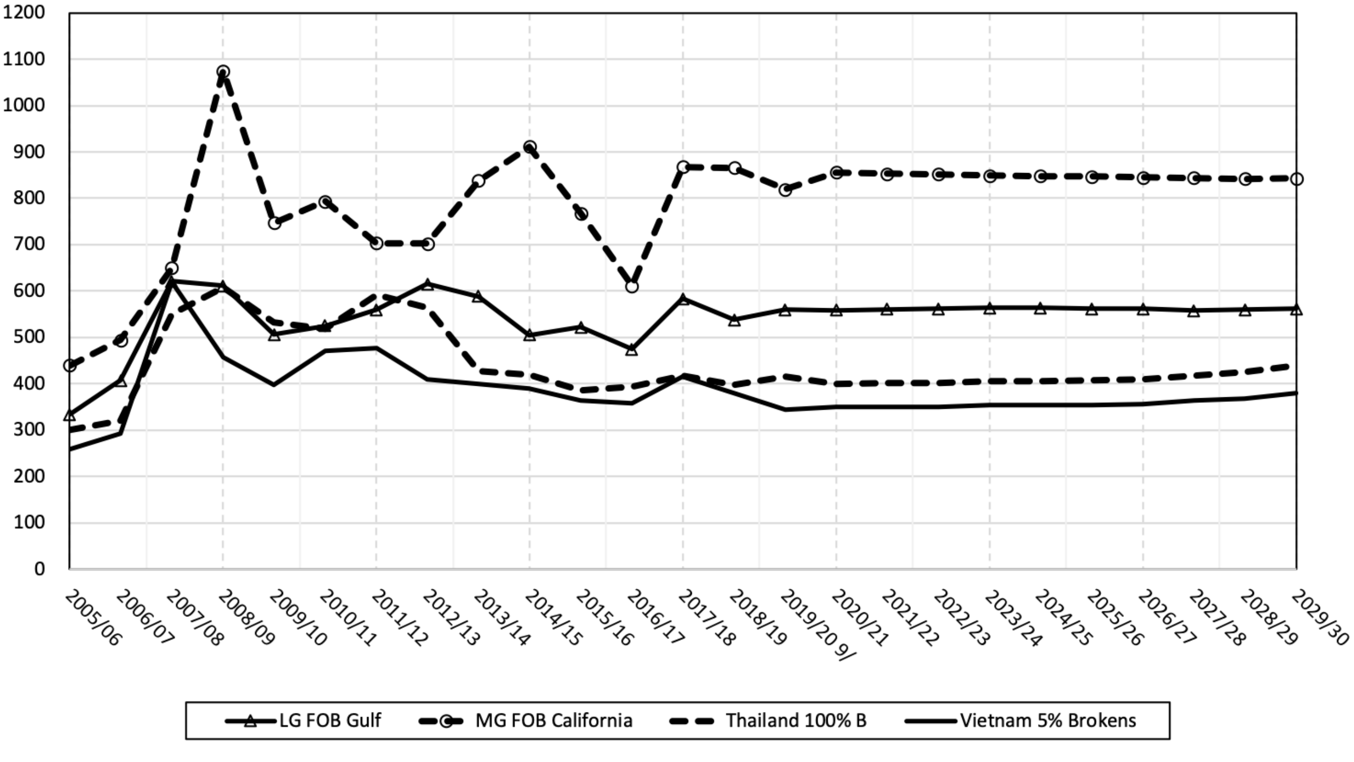

Fig. 2. Annual Historical and Projected U.S. and Asian milled rice prices, US$ per metric ton, 2005-2029. Source: USDA-ERS Rice Outlook, January 2020.

Estimating Rice Acreage Response to Major Attributing Factors in Eastern Arkansas

T.K. Gautam[1] *and K.B. Watkins*[1]

Abstract

Eastern Arkansas contributes around 98% of Arkansas' rice production. However, increasing production costs, diminishing net returns, and declining groundwater availability induced by large groundwater withdrawals and climatic variation have imposed some threats to the sustainability of rice farming. This study estimates eastern Arkansas rice acreage response with price change, climatic variation, and groundwater status by employing a fixed-effects model of panel data. The estimated results show a significant positive effect of own price (rice price), a negative impact of soybean and corn price, a positive impact of groundwater increase, and a positive effect of drought index to rice acreage allocation. The own price, soybean price, and corn price elasticities of rice acreage are +1.12, -1.02, and -0.31, respectively. With all other things remaining the same, a one-unit increase in drought index and a one-foot increase in groundwater level induce producers to increase rice acreage by 5.3% and 2.6%, respectively. Likewise, precipitation has a significant positive effect on rice acreage, but at a decreasing rate. The findings of this study could be useful in policy formulation concerning sustainable rice farming, water resource management, and climatic risk mitigation. A balanced policy that ensures sustainable profit margins, encourages water conservation, and mitigates climatic risk would be desirable for sustainable rice farming.

Introduction

Arkansas rice acreage shows an increasing trend over the period from 1970 to 2019 (Fig. 1). However, it shows a dampening trend over the period from 2005 to 2019, as indicated by USDA-NASS survey data (2020). The acreage change might be due to the lower marginal profit compared to competing crops, resource shortage, or unfavorable climatic variation. Rice production in Arkansas primarily relies on groundwater sources for irrigation. At the same time, groundwater reports indicate significant declines in groundwater levels in the Mississippi River Valley alluvial aquifer (MRVAA), which is the primary source of irrigation water. In eastern Arkansas, rice, soybeans, corn, and cotton are major competing crops appropriate on soil type. However, rice and soybeans are the most suitable rotation crops and optimally grown in this region.

The sustainability of rice farming is very important for the economy of the region and the state, as indicated by the fact that this region produces around 98% of rice in the state, and rice sector accounts for more than 25,000 jobs. It is imperative to evaluate the Arkansas rice acreage response to prices, acreage of competing crops, groundwater status, and climatic variation. The main objective of this study is to estimate the rice acreage response with major attributing factors in eastern Arkansas and suggest some policy implications that would be helpful in water conservation, climatic risk mitigation, and sustainable rice farming. We used data from the period 1970 to 2018 to estimate the acreage responsiveness.

Procedures

This study uses a fixed-effects model of panel data to estimate the eastern Arkansas rice acreage response with major attributing factors. For the model specification, let us consider the following general form of panel data model:

$$y_{it} = x'_{it}\beta + u_{it} \qquad \text{Eq. 1}$$

Here, y is the vector of the dependent variable (acres of rice planted), i represents counties (i = 1,2,…n), t represents year, x is the vector of explanatory variables (own price, competing crop prices, competing crops acreage, precipitation, drought index, and groundwater level change), and $u_{it} = (\varepsilon_{it} + c_i)$ is the error term. The error term consists of two terms in which c_i represents individual-specific effects that are fixed over time, and ε_{it} is the time-variant error term. The major concern in this set up is that the unobserved random effect c_i is correlated with explanatory variables, which creates an endogeneity problem. In order to account for this problem, we need to use an instrumental variable (IV) or other alternative approaches. As an alternative to an IV method, we can estimate the parameter consistently applying one of the approaches: 1) within-group estimator, 2) least square dummy variable estimator, and 3) first difference estimator (Wooldridge, 2010). We use the first difference estimator in fixed-effects model. First differencing eliminates the unobserved individual-specific error term c_i. The fixed-effects model controls for all time-invariant differences between the individuals, so the estimated coefficients of the fixed-effects models cannot be biased because of omitted time-invariant characteristics

Data used in this study are obtained from three different sources. Acreage and price information for rice, soybean, corn, and cotton are obtained from the United States Department of Agriculture, National Agricultural Statistical Services (USDA-NASS), and the United States Department of Agriculture Economic Research Services (USDA- ERS). Precipitation and drought index data are obtained from the National Oceanic and Atmospheric Administration (NOAA), and groundwater level

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[1] Program Associate and Professor, respectively, Department of Agricultural Economics and Agribusiness, Rice Research and Extension Center, Stuttgart.

change data are obtained from the Arkansas Natural Resource Commission (ANRC 2004–2018). Crop acreage, price, and climatic information include data for the period 1970 to 2018, but groundwater data is from the period 2004 to 2018 only.

Results and Discussion

Summary statistics along with variables description are presented in Table 1. The drought index variable "Palmer Drought Severity Index" (PDSI) represents the wet or dry condition of each county over time. It ranges from +6 to -6, in which negative values indicate severity of drought and positive values indicate wet conditions. Estimated results presented in Table 2 show the effects of the own price, soybean price, and corn price on the elasticity of rice acreage are 1.12, -1.03, and -0.31, respectively. It implies that a 1% increase in own price induces producers to increase rice acreage by 1.13%, and a 1% increase in soybean price induces producers to decrease rice acreage by 1.03%. Our estimated own price elasticity seems to be higher than that was found by Chowdhury (2002) for California (0.59) and Texas (0.81). Our findings of statistically significant positive own price elasticity and negative competing crop price elasticities are consistent with economic theory and the results found by Haile et al. (2016) in a global context using cross country data over the period of 1961–2010. The impact of cotton price is unimportant mainly because it is not a better rotating crop for rice.

The impact of climatic variations and groundwater level change have a statistically significant positive impact on rice acreage (significant at 1% significance level). For example, all else remaining constant, a one-foot of groundwater level rise tends to increase rice acreage by 2.6%, and a one-point increase in drought index increases rice acreage by 5.3%. Rice is a highly water intensive crop that requires an adequate and reliable water source available for its sustainable farming. However, if the current trend of groundwater decline continues at the same pace, rice farming may suffer adversely. Thus, groundwater conservation and irrigation efficiency enhancement effort is essential. It has been revealed empirically that producers are over-applying irrigation water by around 37% in Arkansas rice production (Watkins et al., 2019). We need to act aggressively and immediately to minimize existing irrigation inefficiency. By doing so, we would be able to minimize other input applications as well, while conserving our invaluable groundwater resources. Regarding rice acreage response with rainfall, the precipitation variable and its squared terms have a statistically significant impact on rice acreage. The nonlinear relationship between precipitation and rice acreage may differ from month to month. However, we have considered average rainfall amount for growing period and the results indicate that precipitation increases rice acreage, but at a decreasing rate. Additionally, lag of rice acreage affects the rice acreage allocation in the current period positively.

Practical Applications

The findings of this study provide evidence of significant responsiveness of rice acreage to changing prices, climatic variation, and groundwater decline. These results have three major implications. First, higher positive own price elasticity and significant negative price elasticity of competing crops indicate that producers would be attracted to rice farming if they receive a reasonable profit margin. For that, market certainty for product supply is desirable. Rice is a staple food for more than half of the world population, so it is a highly demanded product worldwide. The quality of Arkansas rice is highly competitive, and more efforts in marketing our product should lead to a more competitive price. Second, reduced groundwater availability jeopardizes rice farming in the long run. To maintain groundwater sustainability, aggressive efforts to minimize irrigation inefficiency and increase water conservation are essential. Lastly, the channeling of best possible weather information to producers would help to minimize climatic risk in rice farming.

Acknowledgments

The authors gratefully acknowledge the rice producers of Arkansas for their support through funds administered by the Arkansas Rice Research and Promotion Board and the University of Arkansas System Division of Agriculture for funding and support of this research.

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Table 1. Descriptive statistics and description of variables used in the analysis.

Variable	Variable description	Obs.	Mean	Std. Dev.
RIC_ACR	Planted acres of rice (1000 acres)	1197	47.69	30.556
SOY_ACR	Planted acres of soybeans (1000 acres)	1165	129.07	63.605
COR_ACR	Planted acres of corn (1000 acres)	1022	8.69	11.172
COT_ACR	Planted acres of cotton (1000 acres)	899	38.86	38.882
RIC_PR[a]	Rice price per hundredweight (dollars per cwt)	1144	8.86	3.019
SOY_PR[a]	Soybean price per hundredweight (dollars per cwt)	1144	7.31	2.367
COR_PR[a]	Corn price per bushel (dollars per bu.)	1144	3.10	1.235
COT_PR[a]	Cotton price per pound (dollars per lb)	1144	0.62	0.116
PDSI	Palmer drought Severity Index (-6 to +6 scale)	1274	0.08	1.832
PREC	Precipitation amount (inch of rainfall)	1274	20.67	5.859
GWD10	Groundwater decline during 10-year period (ft)	389	-3.45	3.674
GWD5	Groundwater decline during 5-year period (ft)1	389	-1.19	2.576
GWD1	Groundwater decline during 1-year period (ft)	389	-0.17	2.072

[a] Crop prices are in normal form (not normalized prices as used in estimation).

Table 2. Estimated coefficient of rice acreage response using fixed-effect method.

Variables	Variable Description	Coefficients
lnRIC_ACR	Log of Lag- planted acres of rice	0.167** (0.075)
lnSOY_ACR	Log of planted acres of soybeans	-0.495*** (0.143)
lnCOT_ACR	Log of planted acres of cotton	-0.027 (0.039)
lnRIC_PR	Log of rice price per hundredweight (dollars per cwt)	1.122*** (0.198)
lnSOY_PR	Log of soybean price per hundredweight (dollars per cwt)	-1.025*** (0.256)
lnCOR_PR	Log of corn price per bushel (dollars per bu.)	-0.310*** (0.0945)
lnCOR_ACR	Log of planted acres of corn	-0.126*** (0.031)
lnCOT_PR	Log of cotton price per pound (dollars per lb)	1.037*** (0.218)
PREC	Growing season’s average rainfall (in.)	0.032** (0.012)
PREC 2	Square of Precipitation	-0.001** (0.0004)
PDSI	Palmer drought Severity Index (-6 to +6 scale)	0.053*** (0.009)
GWD1	Groundwater level change during 1-year period (ft)	0.026*** (0.007)
C	Constant	16.310*** (2.209)

Notes: robust standard errors in parentheses; asterisks ***, **, and * represent statistical significance at the 1%, 5%, and 10% levels, respectively. Planted acres and prices are in natural logarithm, prices are normalized by the producer price index (PPI) to 2015 dollars.

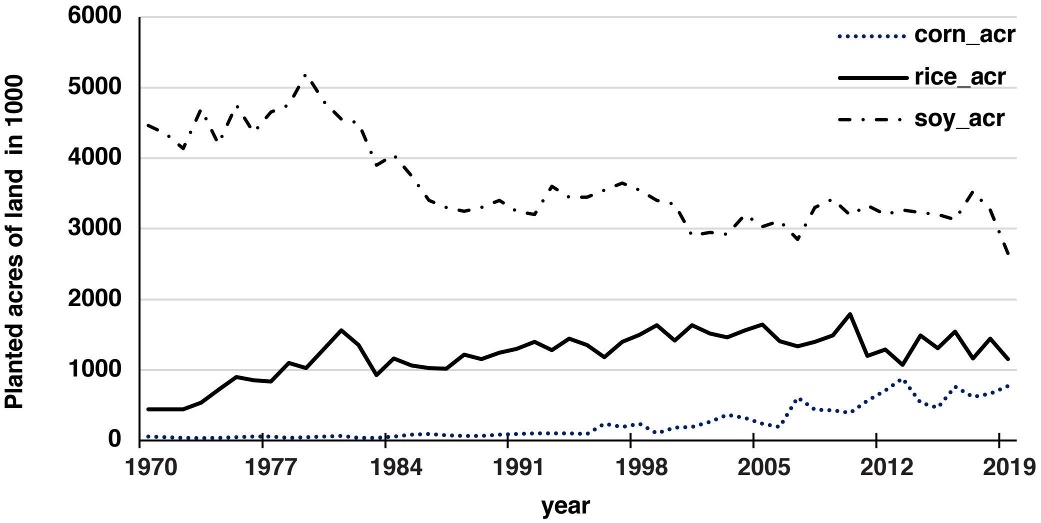

Fig. 1. Planted acres of rice, soybean, and corn in Arkansas over the period 1970–2019.

Rice Enterprise Budgets and Production Economic Analysis

B.J. Watkins[1]

Abstract

Crop enterprise budgets are developed that are flexible for representing alternative production practices of Arkansas producers. Interactive budget programs apply methods that are consistent over all field crops. Production practices for base budgets represent University of Arkansas System Division of Agriculture Cooperative Extension recommendations from crop specialists, researchers, and from the University of Arkansas System Division of Agriculture Rice Research Verification Program. Unique budgets can be customized by users based on either Extension recommendations or information from producers for their production practices. The budget program is utilized to conduct economic analysis of field data in the Rice Research Verification Program. The crop enterprise budgets are designed to evaluate 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

Technologies are continually changing for rice production. Simultaneously, volatile commodity prices and steadily increasing input prices present challenges for producers to maintain profitability. Producers need the means to calculate costs and returns of production alternatives to estimate potential profitability. The objective of this research is to develop an interactive computational program that will enable stakeholders of the Arkansas rice industry to evaluate production methods for comparative costs and returns.

Procedures

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

Ownership costs and repair expenses for machinery are estimated by applying engineering formulas to representative prices of new equipment (Givan, 1991; Lazarus and Selly, 2002). Repair expenses in crop enterprise budgets should be regarded as value estimates of full-service repairs. Repairs and maintenance performed by hired farm labor will be partially realized as wages paid to employees. Machinery performance rates of field activities utilized for machinery costs are used to estimate time requirements of an activity which is applied to an hourly wage rate for determining labor costs (USDA-NASS, 2019). Labor costs in crop enterprise budgets represent time devoted to specified field activities but do not include irrigation labor expenses.

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 in September 2019. Representative prices for machinery and equipment are based on contacts with Arkansas dealers, industry list prices, and reference sources (Deere & Company 2019; MSU, 2019). Revenue in crop enterprise budgets is the product of expected yields from following Extension practices under optimal growing conditions and commodity prices received data.

Results and Discussion

The University of Arkansas System Division of Agriculture Department of Agricultural Economics and Agribusiness (AEAB) and Cooperative Extension Service 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 University of Arkansas System Division of Agriculture Department of Crop, Soil, and Environmental Sciences. Actual production practices vary greatly among individual farms due to management preferences and between production years due to climatic conditions. Analyses are for generalized circumstances with a focus on consistent and coordinated application of budget methods for all field crops. This

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[1] Instructor, Conservation and Crop Budget Economist, Agriculture and Natural Resources, Jonesboro.

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.

Figure 1 presents an example of a 2019 crop enterprise budget for Arkansas dry-seeded, delayed-flood conventional rice. Costs are presented on a per-acre basis and with an assumed yield of 170 bushels at a $4.80/bushel price received. Program flexibility allows users to change total acres, as well as other variables to represent unique farm situations. Returns to total specified expenses are $65.72/acre. The budget program includes similar capabilities for Clearfield, hybrid, Clearfield hybrid, and water-seeded rice production.

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

This research is made possible by funding from the University of Arkansas System Division of Agriculture, the Arkansas Rice Checkoff Program administered by the Arkansas Rice Research and Promotion Board, and the USDA ARS Natural Resources Conservation Service.

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Crop Value	**Grower %**	**Unit**	**Yield**[a]	**Price/Unit**	**Revenue**
Crop Value, Enter Expected Farm Yield & Price	100%	bu.	170.00	4.80	816.00
Operating Expenses		**Unit**	**Quantity**	**Price/Unit**[b]	**Costs**
Seed, Includes Applicable Fees	100%	acre (ac)	1	36.72	36.72
Nitrogen 100%	100%	Lb	152	0.38	57.75
Phosphate (0-46-0)	100%	lb	87	0.19	16.75
Potash (0-0-60)	100%	lb	100	0.17	17.25
Ammonium Sulfate (21-0-0-24)	100%	lb	0	0.16	0.00
Boron 15%	100%	lb	0.00	0.60	0.00
Agrotain, Other Nutrients	100%	Ac	1.00	9.09	9.09
Herbicide	100%	ac	1	111.92	111.92
Insecticide	100%	ac	1	8.00	8.00
Fungicide	100%	ac	1	25.43	25.43
Other Chemical	100%	ac	1	0.00	0.00
Other Chemical	100%	ac	1	0.00	0.00
Custom Chemical & Fertilizer Applications					
Ground Application: Fertilizer & Chemical	100%	ac	0	7.50	0.00
Air Application: Fertilizer & Chemical	100%	ac	5	8.00	40.00
Air Application: Lbs.	100%	lb	330	0.080	26.40
Other Custom Hire, Air Seeding	100%	ac	0	8.00	0.00
Machinery and Equipment					
Diesel Fuel, Pre-Post Harvest	100%	Gallons	4.363	2.50	10.91
Repairs and Maintenance, Pre-Post Harvest	100%	ac	1	6.96	6.96
Diesel Fuel, Harvest	100%	Gallons	3.082	2.50	7.70
Repairs and Maintenance, Harvest	100%	ac	1	11.59	11.59
Irrigation Energy Cost	100%	ac-in.	30	2.95	88.58
Irrigation System Repairs & Maintenance		ac-in.	30	0.24	7.20
Supplies (ex. polypipe)	100%	ac	1	0.00	0.00
Levee Gates	100%	ac	1	0.70	0.70
Labor, Field Activities	100%	Hours	0.909	11.33	10.30
Scouting/Consultant Fee	100%	ac	1	8.00	8.00
Other Expenses	100%	ac	1	0.00	0.00
Crop Insurance	100%	ac	1	10.00	10.00
Interest, Annual Rate Applied for 6 Months	100%	Rate %	5.50	511.25	14.06
Custom Harvest	100%	ac	0.00	0.00	0.00
Post-Harvest Expenses					
Drying	100%	bu.	170.00	0.40	68.00
Hauling	100%	bu.	170.00	0.19	32.30
Check Off, Boards	100%	bu.	170.00	0.01	2.30
Cash Land Rent		ac	1	0.00	0.00
Total Operating Expenses					**$627.90**
Returns to Operating Expenses					**$188.10**
Capital Recovery & Fixed Costs					
Machinery and Equipment		ac	1	77.01	77.01
Irrigation Equipment		ac	1	41.52	41.52
Farm Overhead[c]		ac	1	3.85	3.85
Total Capital Recovery & Fixed Costs					**$122.38**
Total Specified Expenses					**$750.28**
Net Returns					**$65.72**

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

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

[c] Estimate based on machinery and equipment.

Fig. 1. 2020 Rice Enterprise Budget, Conventional Seed.

Impacts of Arkansas Rice Foundation Seed Sales on Arkansas Rice Acres

K.B. Watkins,[1] D.K. Ahrent Wisdom,[1] T.K. Gautam,[1] and G.R. Bathke[1]

Abstract

The primary goal of the University of Arkansas System Division of Agriculture's Arkansas Rice Foundation Seed Program is to make rice seed of newly released and proven cultivars available to Arkansas growers as quickly as possible. Foundation seed is then sold to certified seed growers who multiply it into either registered or certified seed for sale to rice producers. This study focuses specifically on the sales of Arkansas pure-line rice foundation seed in Arkansas. The objective is to evaluate the impact of Arkansas rice foundation seed sales on acres of public and proprietary rice lines in Arkansas. Seemingly unrelated regression was used to evaluate the impacts of Arkansas rice foundation seed sales on both public (pure-line) acres and proprietary (Clearfield and hybrid) acres since 2000. The results indicate the sale of Arkansas rice foundation seed has significant impacts on Arkansas rice acres, and these impacts vary depending on the types of rice cultivars grown.

Introduction

The Arkansas Rice Foundation Seed Program is responsible for the production of rice foundation seed and for assisting breeders in the production of breeder seed. Its primary goal is to make the seed of newly released and proven varieties available to Arkansas growers as quickly as possible. The Arkansas Rice Foundation Seed Program is administered by the Arkansas Agricultural Experiment Station and is based at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center near Stuttgart, Arkansas. This study focuses specifically on sales of Arkansas pure-line rice foundation seed in Arkansas. The objective is to evaluate the impact of Arkansas rice foundation seed sales on acres of public and proprietary rice lines in Arkansas. Public rice lines include Arkansas and Non-Arkansas pure-lines, while proprietary rice lines include Clearfield cultivars and hybrid cultivars (conventional hybrids and Clearfield hybrids).

Procedures

This study used harvested rice acres by cultivar data from various proceedings of the biannual Rice Technical Working Group meeting (RTWG, various years), rice foundation seed sales data from the Arkansas Rice Foundation Seed Program, and registered rice cultivar release data from the Arkansas Rice Performance Trials (ARPT) program (UAEX, various years) for the years 2000 through 2018. Harvested rice acres by cultivar were separated into four different rice cultivar types: 1. Arkansas Pure-Lines; 2. Non-Arkansas Pure-Lines; 3. Clearfield Lines; and 4. Hybrid Lines (conventional hybrids and Clearfield hybrids).

Rice foundation seed sales data from the Arkansas Rice Foundation Seed Program include the number of 50-pound bags of Arkansas rice foundation seed sold per year. The number of bags sold per year included bags of Arkansas pure-line seed sold exclusively in Arkansas. Bags of Arkansas pure-line seed sold outside of Arkansas were excluded from the analysis.

Registered rice cultivar release data are defined as the number of registered Arkansas rice cultivars released per year. When a new rice cultivar is publically released as foundation seed, it is given a name, and its complete description is registered with the National Committee on Registration of Crop Varieties. The number of registered rice cultivars released per year was quantified in this study for the period 2000–2018. These data were then used to determine the impacts of the number of registered rice cultivars released per year on Arkansas rice acres.

Seemingly unrelated regression was used to evaluate the impacts of Arkansas rice foundation seed sales on both public and proprietary rice acres planted since 2000. Seemingly unrelated regression is a method for pooling time-series and cross-sectional data exhibiting contemporaneous correlation in the disturbance terms and assumes each cross-sectional unit has a different coefficient vector (Judge et al., 1988). In this study, the cross-sectional units are the four rice cultivar types. Independent variables for each regression equation included trend, trend squared, the number 50-pound bags of Arkansas rice foundation seed sold lagged one year, and the number of registered Arkansas pure-lines released per year.

Results and Discussion

Arkansas harvested rice acres are presented by rice cultivar type for the period 2000–2018 in Fig. 1. In the early years of this period (from 2001–2007), Arkansas pure-lines controlled most rice acres, accounting for nearly half of all harvested acres. The cultivars Wells and Francis accounted for most acres grown in Arkansas pure-lines during this period. Non-Arkansas pure-lines and proprietary Clearfield lines occupied nearly all remaining rice acres during the 2000–2007 period. Most rice acres planted to non-Arkansas pure-lines were occupied by Louisiana cultivars (Bengal, Cheniere, Cocodrie, Cypress).

From 2008 through 2018, both Arkansas and non-Arkansas pure-lines lost ground to hybrid lines. Hybrid lines in this analysis consist of both conventional hybrids and Clearfield hybrids. The

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[1] Professor, Program Associate, Program Associate, and Program/Project Director, respectively, Rice Research and Extension Center, Stuttgart.

latter of the two, Clearfield hybrids, accounted for the majority of hybrid acres grown during the 2008–2018 period. The Wells cultivar continued to remain strong among the Arkansas pure-lines throughout most of 2008–2018 period, while the Francis cultivar gave way to Roy J. (2011–2017) and later to Diamond (2017, 2018). During this same time frame, Non-Arkansas pure-line acres were reduced primarily to medium-grain varieties (Bengal and Jupiter in 2008–2010; primarily Jupiter in 2011–2018) and the long-grain variety Mermentau (2014–2016).

Summary statistics of the number of bags of Arkansas pure-line foundation seed sold in Arkansas during the period 2000–2018 are presented in Table 1. The mean number of bags sold is 5017, but the number of bags sold varied greatly over the 19-year period, ranging from a minimum of 1804 bags in 2013 to a maximum of 11,194 bags in 2004. The median or midpoint number of bags sold is 3635 and is lower than the mean, indicating the mean is skewed upward by a few years in which a relatively large number of bags were sold. Bags sold exceeded the mean in 9 out of 19 years, with most of these years (7 out of 9) occurring during the 2000–2006 period. In more recent years, bags sold exceeded the mean twice (2017 and 2018).

Summary statistics of the number of registered Arkansas rice cultivars released annually during the 2000–2018 period are also presented in Table 1. The mean number of registered releases is below 1 (0.74), indicating registered releases did not occur every year. This is also demonstrated by the median equaling zero. No new registered cultivars were released in 10 of the 19 years evaluated. These statistics reveal the fact that development of newly registered rice cultivars is a complex and time-consuming process. Alternatively, three years had more than one registered release (3 released in both 2004 and 2009; two released in 2016).

Seemingly unrelated regression (SUR) results of Arkansas rice harvested acres by rice cultivar type regressed against trend, lagged annual rice foundation seed bags sold, and number of registered rice cultivars released per year are presented in Table 2. The trend squared term was included in determining if trend in harvested acres for a particular rice cultivar type was non-linear (quadratic) over the 19-year period. A significant trend squared term would indicate a quadratic trend in rice cultivar type acres exists over time. Arkansas pure-line foundation seed bags sold were lagged one year because foundation seed sold to certified seed growers in the present year (t) will be multiplied into both registered and certified seed to be sold to rice producers in the following year ($t + 1$). Thus foundation seed sold this year to certified seed growers will not affect rice acres devoted to a particular rice cultivar type until the following year.

Results of the SUR analysis revealed significant downward trends in both Arkansas and non-Arkansas pure-line acres. The downward trend was quadratic for non-Arkansas pure-line acres (decreasing at an increasing rate) while the downward trend for Arkansas pure-line acres was linear (decreasing at a constant rate). Both cultivar types lost ground to proprietary rice cultivars during the 19-year period. Clearfield acres experienced a significant upward quadratic trend (increasing at a decreasing rate), while hybrid acres experienced a significant upward linear trend (increasing at a constant rate) over the 19-year period.

The number of registered Arkansas pure-lines released per year had a significant and positive impact on Arkansas pure-line acres, with an increase of 47,471 Arkansas pure-line acres for every new registered Arkansas pure-line rice cultivar release. The number of Arkansas pure-lines released per year also had a positive impact on acres of the other three cultivar types, but in every case the increase was not statistically significant.

The number of lagged Arkansas rice foundation seed bags sold had a significant positive impact on Arkansas pure-line acres and a significant negative impact on both Non-Arkansas pure-line acres and hybrid acres. For every bag of lagged foundation seed sold, Arkansas pure-line acres increased by 40 acres while Non-Arkansas pure-line acres and Hybrid acres decreased by 18 and 22 acres, respectively. Lagged Arkansas rice foundation seed bags sold had a positive impact on Clearfield acres (a 9-acre increase for every lagged bag of Arkansas rice foundation seed sold), but the impact was not statistically significant.

Practical Applications

The results of this study indicate the sale of Arkansas rice foundation seed has significant impacts on Arkansas rice acres, and these impacts vary depending on the types of rice cultivars grown. Arkansas rice acres devoted to Arkansas pure-line cultivars increase by 40 acres for every 50-pound bag of Arkansas pure-line rice foundation seed sold. Alternatively, Arkansas rice acres devoted to non-Arkansas pure-lines and hybrid lines decrease by 18 and 22 acres, respectively, for every 50-pound bag of Arkansas pure-line rice foundation seed sold in the state. These findings highlight the importance of the Arkansas Rice Foundation Seed Program as a clean and dependable source of rice seed for rice producers in the state.

Acknowledgments

The authors gratefully acknowledge the funding and support from the rice producers of Arkansas through the monies administered by the Arkansas Rice Research and Promotion Board and the University of Arkansas System Division of Agriculture for funding this research.

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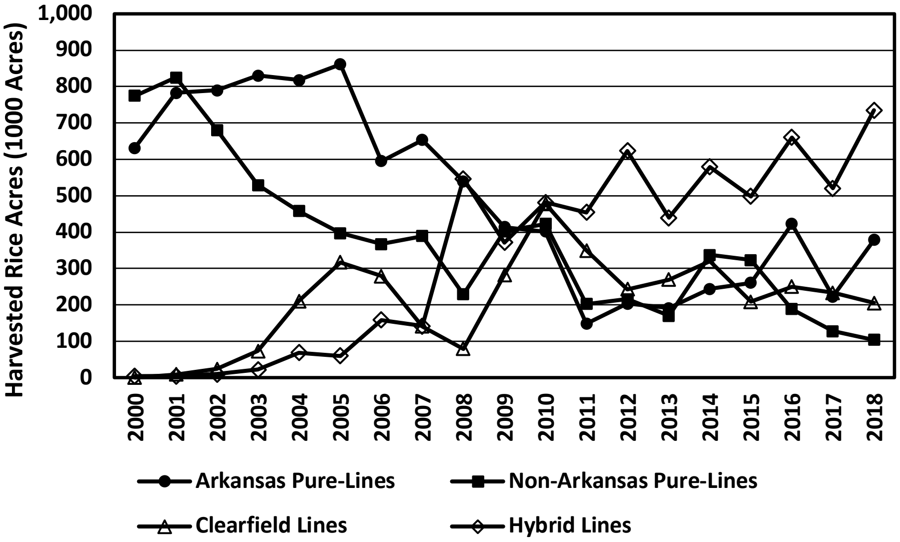

Fig. 1. Arkansas harvested rice acres by rice cultivar type, 2000–2018. Source: Compiled from various biannual publications of the Proceedings of the Rice Technical Working Group (RTWG, various years).

Table 1. Summary statistics of the number of 50-pound bags of Arkansas pure-line rice foundation seed sold and the number of registered Arkansas rice cultivars released per year, 2000–2018.

Statistic	Bags rice foundation seed sold per year[a]	Registered rice cultivars released per year[b]
Mean	5009	0.74
Standard Deviation	2678	0.99
Minimum	1804	0
Median	3635	0
Maximum	11,194	3

[a] Data from the University of Arkansas System Division of Agriculture's Arkansas Rice Foundation Seed Program. Includes bags of Arkansas pure-line foundation seed sold exclusively in Arkansas. Bags of Arkansas pure-line seed sold outside of Arkansas were excluded from the analysis.

[b] Data from the Arkansas Rice Performance Trials (ARPT). Data do not include Clearfield lines developed from Arkansas rice cultivars.

Table 2. Seemingly unrelated regression results of Arkansas rice harvested acres by rice cultivar type regressed against trend, lagged annual 50-pound rice foundation seed bags sold, and number of registered rice cultivars released per year.

Variable	Arkansas Pure-Line Acres		Non-Arkansas Pure-Line Acres		Clearfield Line Acres		Hybrid Line Acres[a]	
Trend (t)[b]	-39,449	**[c]	-84,970	***	67,425	***	46,587	***
	(16,205) [d]		(12,971)		(13,662)		(14,979)	
Trend Squared (t^2)	686	NS	2,410	***	-2620	***	-457	NS
	(758)		(607)		(639)		(701)	
Lagged Seed Bags Sold (t -1)[e]	40	***	-18	**	9	NS	-22	***
	(9)		(7)		(8)		(9)	
Registered Cultivars Released (t)	47,471	**	20,289	NS	23,888	NS	2,379	NS
	(20,611)		(16,497)		(17,377)		(19,052)	
Constant	560,362	***	990,662	***	-190,192	**	44,094	NS
	(105,095)		(84,120)		(88,604)		(97,146)	
R^2	0.8709		0.8836		0.6542		0.9019	

[a] Hybrid lines include both conventional hybrids and Clearfield hybrids.

[b] t = year, where year 1 = “2000”, year 2 = “2001”, …, year 19 = “2018”.

[c] Asterisks ***, **, and * represent statistical significance at the 1%, 5%, and 10%, respectively. “NS” = not significant.

[d] Numbers in the parentheses are standard errors.

[e] $t – 1$ = lagged one year (foundation seed sales from previous year).

2019-2020 Rice Research Proposals

Principal Investigator (PI)	Co-PI	Proposal Name	Year of Research	Funding Amount (US$)
Non-Ecosystems				
K. Moldenhauer		Breeding and evaluation for improved rice varieties	3 of 3	355,000
K. Moldenhauer	X. Sha and E. Shakiba	Quality analysis for rice breeding and genetics	3 of 3	140,000
X. Sha		Development of superior medium-grain and long-grain rice varieties for Arkansas and the mid-south	3 of 3	350,000
E. Shakiba		Breeding and evaluation for hybrid rice adapted to the southern USA	2 of 3	210,000
E. Shakiba	K. Moldenhauer and X. Sha	Marker-assisted selection for advanced rice breeding and genetics	3 of 3	160,000
J. Hardke		Arkansas rice performance trials	3 of 3	99,000
K. Moldenhauer	Y. Wamishe	Rice breeding and pathology tech support	3 of 3	140,000
Y. Wamishe	J. Hardke	Evaluation of contemporary rice to straighthead, a physiological disorder of unknown cause	1 of 3	10,000
C. Rojas	A. Pereira	Investigating genetic basis of resistance to bacterial panicle blight of rice under heat stress conditions	1 of 3	32,000
C. Rojas	Y. Wamishe, A. Rojas and T. Spurlock	Control of rice diseases in Arkansas by using antagonistic bacteria and products derived from them	1 of 3	35,000
A. Pereira	P. Counce and K. Moldenhauer	Improving grain yield and quality under high nighttime temperature using functional gene markers	3 of 3	40,000
T. Roberts		Soil amendment and management techniques to reduce heavy metal concentrations in rice	1 of 3	50,000
J. Hardke	B. Watkins	Rice research verification program	3 of 3	195,000
T. Siebenmorgen		Identification of cultivar attributes that impact rice drying and milling characteristics	1 of 3	75,000
R. Norman		Editing and publishing B.R. Wells Rice Research studies (2018)		10,000
V. Ford	B. Watkins	Rice enterprise budgets and production economic analysis	1 of 1	10,000
A. Durand-Morat	B. Watkins and R. Mane	Analysis of farm policy programs and competitiveness of Arkansas and U.S. rice	3 of 3	15,000
J. Hardke	T. Roberts	Agronomics of alternative irrigation strategies	3 of 3	95,000
C. Henry	R. Mane, D. Pickelman, G. Simpson, J. Rix and K. Brye	Developing and improving irrigation tools for rice	3 of 3	95,000
M. Reba		Effect of residue management on planting readiness	2 of 3	10,000
			Total Non-Ecosystem Funding:	**2,126,000**

Continued

2019-2020 Rice Research Proposals, continued.

Principal Investigator (PI)	Co-PI	Proposal Name	Year of Research	Funding Amount (US$)
Ecosystems				
T. Barber	J. Norsworthy and T. Butts	A team approach to improved weed management in rice	3 of 3	281,000
J. Hardke		Agronomic production practices for rice	3 of 3	115,000
J. Hardke		DD50 Thermal unit thresholds and seeding date effects for new cultivars	3 of 3	70,000
J. Hardke		Optimum rice plant spacing and seeding rate	1 of 3	30,000
T. Roberts		Soybean maturity group and yield influences nitrogen credits for rice	3 of 3	25,000
J. Hardke	T. Roberts	Nitrogen recommendations for new rice cultivars	1 of 3	66,000
G. Lorenz	N. Bateman, and B. Thrash	Rice insect control	3 of 3	135,000
T. Roberts		Nitrogen management tools for Arkansas rice producers	1 of 3	125,000
T. Roberts		Rice fertilization–developing novel methods to assess nutrient availability	3 of 3	67,000
Y. Wamishe	J. Hardke	Evaluation of fungicide application timing and coverage to suppress false smut and sheath blight of rice	3 of 3	30,000
Y. Wamishe	T. Mulaw	Scale up of technology for applications of patent pending Trichoderma, strain TM17 as based preparations of biocontrol agents to rice diseases	1 of 3	45,000
B. Watkins	A. Durand-Morat	Economic analysis of Arkansas rice farms	3 of 3	66,000
			Total Ecosystem Funding:	**1,055,000**
			Total Ecosystem and Non-Ecosystem:	**3,181,000**

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