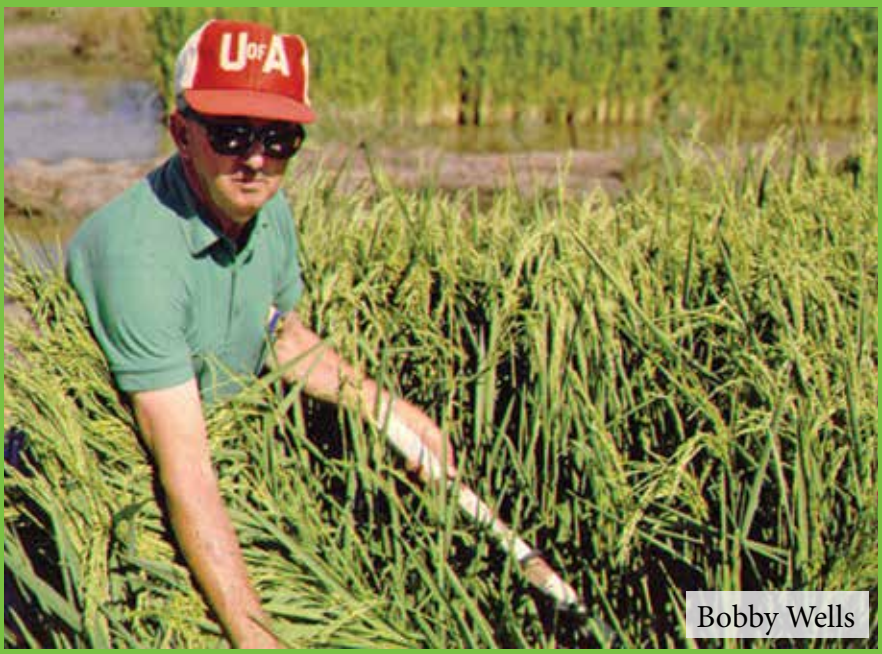
25th Anniversary Edition

B.R. Wells

Arkansas Rice Research Studies 2015



Bobby Wells

R.J. Norman and K.A.K. Moldenhauer, editors

UofA DIVISION OF AGRICULTURE
RESEARCH & EXTENSION
University of Arkansas System

ARKANSAS AGRICULTURAL EXPERIMENT STATION

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Cover Photo: Bobby Wells evaluating a rice study for nutrient deficiencies (circa 1985). Photo credit: University of Arkansas System Division of Agriculture.

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University of Arkansas System
Division of Agriculture
Arkansas Agricultural Experiment Station
Fayetteville, Arkansas 72701

DEDICATED IN MEMORY OF

Bobby R. Wells

Bobby R. Wells was born July 30, 1934, at Wickliffe, Ky. 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 on rice nutrition and soil fertility. He 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 and chairman of the RTWG. He loved being a professor and was an outstanding teacher and a mentor to numerous graduate students. Wells developed an upper-level course in rice production and taught it for many years. He was appointed head of the Department of Agronomy in 1993 and was promoted to the rank of University Professor that year in recognition of his outstanding contributions to research, service, and teaching.

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 was awarded, posthumously, the Distinguished Service Award from the RTWG (1998).

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.

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.

CONTENTS

OVERVIEW AND VERIFICATION

BREEDING, GENETICS, AND PHYSIOLOGY

PEST MANAGEMENT: DISEASES

PEST MANAGEMENT: INSECTS

PEST MANAGEMENT: WEEDS

RICE CULTURE

RICE QUALITY AND PROCESSING

ECONOMICS

Trends in Arkansas Rice Production, 2015

J.T. Hardke[1]

ABSTRACT

Arkansas is the leading rice-producing state in the United States. The state represents 49.0% of total U.S. rice production and 50.0% of the total acres planted to rice in 2015. 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 Rice Degree-Day 50 (DD50) Program was included to summarize variety acreage distribution across Arkansas. Other data was obtained from the USDA National Agricultural Statistics Service.

INTRODUCTION

Arkansas is the leading rice-producing state 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.

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

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 (USDA-NASS, 2016). Rice cultivar distribution was obtained from summaries generated from the University of Arkansas System Division of Agriculture's Rice Degree-Day 50 (DD50) program enrollment.

RESULTS AND DISCUSSION

Rice acreage by county is presented in Table 1 with distribution of the most widely produced cultivars. RiceTec CLXL745 was the most widely planted cultivar in 2015 at 19.9% of the acreage, followed by RiceTec XL753 (14.5%), Jupiter (14.4%), Roy J (13.1%), CL151 (12.4%), LaKast (5.0%), Mermentau (4.1%), CL111 (3.8%), RiceTec CLXL729 (3.2%), and Wells (1.6%). Additional cultivars of importance in 2015, though not shown in the table, were CL271, RiceTec XL723, Francis, Taggart, CL152, and Caffey.

Arkansas producers planted 1,306,000 acres of rice in 2015 which accounted for 50.0% of the total U.S. rice crop in 2015 (Table 2). The State's average yield of 7340 lb/acre (163 bu/acre) represented a 220 lb/acre reduction compared to 2014. Despite the decline, average yields in Arkansas still represented the second highest average in the U.S. behind California in 2015. In addition, 2015 average yields for Arkansas (163 bu/acre) were the fourth highest on record behind 2013 (168 bu/acre), 2014 (168 bu/acre), and 2012 (166 bu/acre). The total rice produced in Arkansas during 2015 was 94.34 million hundredweight (cwt). This represents 49.0% of the 192.3 million cwt produced in the U.S. during 2015. Over the past 3 years, Arkansas has produced 47.3% of all rice produced in the U.S. The six largest rice-producing counties in Arkansas during 2015 included Poinsett, Lawrence, Arkansas, Cross, Jackson, and Lonoke, representing 41.7% of the state's total rice acreage (Table 1).

Planting in 2015 started behind the 5-year state average due to cold, wet conditions throughout March and April (Fig. 1). Planting progress was only 37% by 26 April in 2015 compared to 59% planting progress averaged across the previous five years. Dry conditions resulted in significant planting progress during the last week of April and first week of May as planting progress jumped from 37% to 86% over this 2-week period. Planting was almost fully complete by 1 June. While planting progress was notably delayed by early-season weather, mild and extremely dry conditions led to harvest progressing at a rate almost identical to the 5-year average (Fig. 2). About 57% of the crop had been harvested by 20 September compared with 56% harvest progress on the same date in the 5-year average. Harvest progress was complete (100%) by 1 November.

Over 60% of the rice produced in Arkansas was planted using conventional tillage methods in 2015 (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 (30.1%) or no-till (6.3%) systems. True no-till rice production is not common but is done in a few select regions of the state.

The majority (53.6%) of rice is still produced on silt loam soils (Table 3). Rice production on clay or clay loam soils (20.6% and 20.9%, 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 72.3% of the rice acreage (Table 3). Approximately 21% of the acreage in 2015 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 utilizing a dry-seeded, delayed-flood system with only 5.5% using a water-seeded system. Annually, approximately 85% of all the Arkansas rice acreage is drill-seeded with the remaining acreage broadcast-seeded (dry-seeded and water-seeded).

Irrigation water is one of the most precious resources for rice producers in Arkansas. Reports of diminishing supplies have prompted many producers to develop reservoir and/or tailwater recovery systems to reduce the "waste" by collecting and re-using 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 76.4% of the rice acreage in Arkansas with the remaining 23.6% 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 2015, rice farmers utilize this practice on 40.6% of the rice acreage (Table 3). Most remaining acreage is still irrigated with conventional levee and gate systems. A small percentage of rice acreage is produced in more upland conditions utilizing furrow irrigation 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 little acreage at this time.

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 2015, 43.5% of the acreage was burned, 39.0% was tilled, 26.7% was rolled, and 20.4% 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, but in 2015 acreage where the stubble was burned noticeably increased as dry fall conditions permitted more of this stubble management practice to take place.

Pest management is vital to preserve both yield and quality in rice. Foliar fungicide applications were made on 52.5% of rice acres in 2015 (Table 3). This number was lower than the previous year as warm and dry late season conditions in southern Arkansas reduced disease development. Nearly 36% of rice acres received a foliar insecticide application due to rice stink bug infestation levels which were low and similar to 2014. Insecticide seed treatments were used on 67.4% of rice acreage as producers continue to adopt this technology more widely each year due to its benefits

for both insect control and improved plant growth and vigor. However, in 2015, use of insecticide seed treatments was likely lower than indicated in this survey as growers attempted to reduce input costs.

Clearfield rice continues to play a significant role in rice production in Arkansas. This technology (all cultivars combined) accounted for 44% of the total rice acreage in 2015 (Fig. 3). This represents a 5% decrease in Clearfield rice acreage compared to 2014 and the fourth consecutive year of acreage decline. 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.

SIGNIFICANCE OF FINDINGS

State average yields over the past 20 years in Arkansas have increased from an average of 120 bu/acre in 1993-1995 to an average of 166 bu/acre in 2013-2015, an increase of 46 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, 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 administered by the Arkansas Rice Research and Promotion Board and the support provided by the University of Arkansas System Division of Agriculture; all of the county agents who participated in this survey; and the members of the Rice Agronomy crew: Donna Frizzell, Eduardo Castaneda-Gonzalez, Garrett Lee, Tara Clayton, Chuck Pipkins, Ralph Mazzanti, and Ron Baker.

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Table 1. 2015 Arkansas

	Harvested acreage[a]		Medium-grain		Long-grain-
County	**2014**	**2015**	**Jupiter**	**Others[b]**	**CL111**
Arkansas	91,155	86,669	6212	3451	2172
Ashley	11,182	9105	981	0	0
Chicot	34,839	27,057	0	617	630
Clay	81,506	69,905	9086	1249	529
Conway	1703	1149	0	0	0
Craighead	71,509	66,874	10,239	7591	14,620
Crittenden	51,036	43,842	3422	3092	0
Cross	88,036	84,001	17,214	480	3073
Desha	25,266	17,226	3539	2196	0
Drew	11,312	9550	1895	474	0
Greene	78,405	66,208	5958	0	0
Independence	12,747	9974	1596	84	2045
Jackson	104,194	82,216	18,707	13,979	1515
Jefferson	72,463	64,767	3607	709	0
Lafayette	4434	3546	0	0	355
Lawrence	99,922	91,554	19,290	0	6699
Lee	29,920	21,744	1431	0	0
Lincoln	21,516	21,016	1782	0	0
Lonoke	89,732	80,916	4799	662	1564
Mississippi	53,540	47,953	1431	0	0
Monroe	59,492	48,728	5711	697	233
Phillips	32,643	16,094	0	543	0
Poinsett	121,569	110,824	34,132	11,351	3503
Pope	2205	2186	0	0	0
Prairie	63,640	61,743	8631	1974	5932
Pulaski	4168	3799	962	0	0
Randolph	35,657	30,009	10,907	0	4503
St. Francis	38,443	37,462	7046	24	275
White	13,192	10,073	2029	0	0
Woodruff	61,925	50,874	4302	1902	1104
Others[c]	7868	2746	0	0	0
Unaccounted[d]	4781	5596			
2015 Total		1,286,000	184,910	51,076	48,751
2015 Percent		100	14.38	3.97	3.79
2014 Total	1,480,000		191,915	19,990	73,412
2014 Percent	100		12.97	1.35	4.96

[a] Harvested acreage. Source: USDA-NASS, 2016.

[b] Other varieties: AB647, Antonio, Caffey, Cheniere, Cocodrie, Della-2, Francis, Jazzman, Jazzman-2, RiceTec CL XL746, RiceTec CL XP4534, RiceTec XL723, RiceTec XP4523, and Taggart.

[c] Other counties: Clark, Franklin, Faulkner, Hot Spring, Little River, Perry, and Yell.

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

harvested rice acreage summary.

Long-grain								
CL151	LaKast	Mermentau	CLXL729	CLXL745	XL753	Roy J	Wells	Others[b]
8315	1747	640	2344	29,216	17,064	7422	0	8086
0	0	0	0	8124	0	0	0	0
4093	0	1350	2528	7914	6775	1786	0	1364
26,138	2929	467	206	23,299	4001	1451	550	0
763	0	0	0	0	0	386	0	0
3457	1898	16,079	0	6842	963	5185	0	0
1572	389	0	3276	11,763	11,182	6161	0	2984
13,097	6568	1249	711	6495	12,437	21,012	0	1724
608	893	1662	0	1153	5096	2078	0	0
0	0	0	0	7181	0	0	0	0
14,655	0	1256	0	21,691	20,377	657	0	1519
2045	0	0	0	2045	818	818	409	0
13,107	4894	519	228	7228	8539	8864	0	4558
8968	6675	0	0	34,851	1241	8717	0	0
355	0	0	0	1418	709	355	0	355
25,054	3228	8942	0	11,751	3083	11,880	0	1628
1341	2041	121	2220	1662	5166	7316	0	445
0	0	0	0	989	15,078	3279	0	0
7536	1033	1564	11262	20,831	18,211	9340	0	4151
4215	3901	1246	0	2098	21,244	2749	11,226	0
838	7017	1071	652	7036	3176	20,399	0	1900
0	2239	11,321	0	1990	0	0	0	0
16,634	6398	103	0	6867	4027	20,646	5504	1692
0	0	0	109	2077	0	0	0	0
1454	2067	2429	4113	12,169	12,199	4938	0	6180
294	0	0	0	1472	589	294	294	0
0	0	0	3659	0	6530	0	0	4409
1922	1446	2237	0	9337	258	11,751	1131	2068
676	0	0	1528	2919	1685	0	0	1236
2294	9045	758	7967	5260	5666	11,080	0	1496
406	51	0	0	815	560	113	775	26
								5596
159,837	64,460	53,015	40,804	256,492	186,673	168,677	19,889	51,415
12.43	5.01	4.12	3.17	19.94	14.52	13.12	1.55	4.00
186,518	3,143	72,426	62,445	326,016	174,626	186,022	42,156	141,330
12.60	0.21	4.89	4.22	22.03	11.80	12.57	2.85	9.55

Table 2. Acreage, grain yield, and production of rice in the United States from 2013 to 2015.[a]

State	Area planted			Area harvested			Yield			Production		
	2013	2014	2015	2013	2014	2015	2013	2014	2015	2013	2014	2015
	(1,000 acres)						(lb/acre)			(1,000 cwt[b])		
Arkansas	1076	1486	1306	1070	1480	1286	7560	7560	7340	80,888	111,957	94,341
California	567	445	423	562	442	421	8480	8580	8890	47,641	37,936	37,441
Louisiana	418	466	420	413	462	415	7300	7130	6940	30,135	32,944	28,791
Mississippi	125	191	150	124	190	149	7400	7420	7110	9176	14,096	10,594
Missouri	159	216	182	156	213	174	7030	6830	7020	10,968	14,540	12,212
Texas	145	150	133	144	146	130	7740	7360	6900	11,145	10,742	8964
U.S.	2490	2954	2614	2469	2933	2575	7694	7576	7470	189,953	222,215	192,343

[a] Source: USDA-NASS, 2016.
[b] cwt = hundredweight.

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

	2013		2014		2015	
Cultural practice	**Acreage**	**% of total**	**Acreage**	**% of total**	**Acreage**	**% of total**
Arkansas rice acreage	**1,070,000**	**100.00**	**1,480,000**	**100.00**	**1,286,000**	**100.00**
Soil texture						
Clay	209,251	19.6	290,508	19.6	264,441	20.6
Clay loam	252,702	23.6	311,721	21.1	268,398	20.9
Silt loam	547,386	51.2	825,486	55.8	689,012	53.6
Sandy loam	45,733	4.3	41,474	2.8	53,116	4.1
Sand	14,928	1.4	10,811	0.7	11,033	0.9
Tillage practices						
Conventional	654,647	61.2	883,586	59.7	818,368	63.6
Stale seedbed	329,807	30.8	482,323	32.6	386,620	30.1
No-till	85,546	8.0	114,090	7.7	81,011	6.3
Crop rotations						
Soybean	759,792	71.0	1,069,283	72.2	930,396	72.3
Rice	225,690	21.1	317,662	21.5	273,627	21.3
Cotton	5586	0.5	4030	0.3	3718	0.3
Corn	45,006	4.2	41,093	2.8	42,343	3.3
Grain sorghum	6810	0.6	11,532	0.8	15,450	1.2
Wheat	13,107	1.2	7222	0.5	852	0.1
Fallow	13,705	1.3	29,178	2.0	19,613	1.5
Other	305	0.0	0	0.0	0	0.0
Seeding methods						
Drill seeded	881,172	82.4	1,250,157	84.5	1,074,460	83.6
Broadcast seeded	183,112	17.1	229,843	15.5	211,540	16.4
Water seeded	32,570	3.0	61,221	4.1	70,302	5.5
Irrigation water sources						
Groundwater	848,435	79.3	1,145,847	77.4	982,419	76.4
Stream, rivers, etc.	111,743	10.4	155,345	10.5	146,202	11.4
Reservoirs	109,822	10.3	178,807	12.1	157,379	12.2
Irrigation methods						
Flood, levees	698,139	65.2	885,796	59.9	731,614	56.9
Flood, multiple inlet	368,092	34.4	585,658	39.6	521,689	40.6
Intermittent (AWD)	--	--	--	--	21,241	1.7
Furrow	3769	0.4	6203	0.4	11,456	0.9
Sprinkler	0	0.0	458	0.0	0	0.0
Other	0	0.0	1885	0.1	0	0.0
Stubble management						
Burned	303,204	28.3	414,650	28.0	559,736	43.5
Tilled	430,519	40.2	537,686	36.3	501,329	39.0
Rolled	316,705	29.6	548,333	37.0	343,383	26.7
Winter flooded	203,971	19.1	294,729	19.9	262,846	20.4

continued

Table 3. Continued.

	2013		2014		2015	
Cultural practice	**Acreage**	**% of total**	**Acreage**	**% of total**	**Acreage**	**% of total**
Land management						
Contour levees	345,944	32.3	402,239	27.2	625,600	48.6
Precision-level	603,039	56.4	896,041	60.5	519,907	40.4
Zero-grade	121,016	11.3	181,720	12.3	141,897	11.0
Precision agriculture						
Yield monitors	553,505	51.7	877,850	59.3	847,603	65.9
Grid sampling	240,490	22.5	437,759	29.6	386,143	30.0
Variable-rate fertilizer	202,822	19.0	367,045	24.8	336,228	26.1
Pest management						
Insecticide seed treatment	653,049	61.0	1,047,204	70.8	867,242	67.4
Fungicide (foliar application)	578,201	54.0	853,570	57.7	674,727	52.5
Insecticide (foliar application)	457,649	42.8	526,939	35.6	462,302	35.9

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

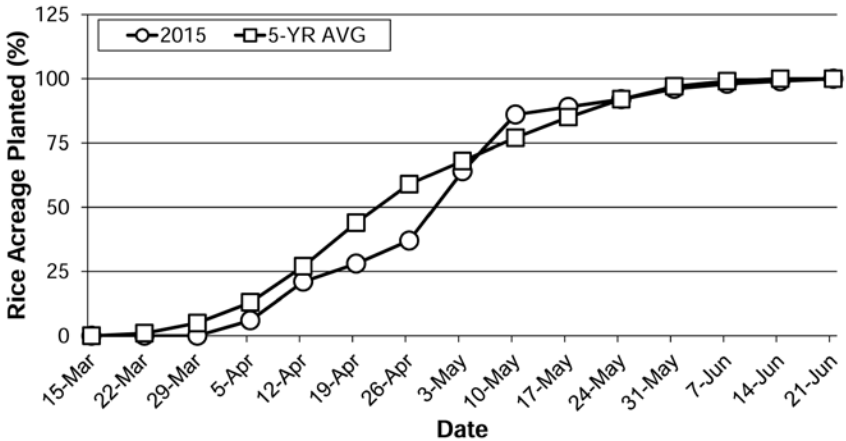

Fig. 1. Arkansas rice planting progress during 2015 compared to the five-year state average (USDA-NASS, 2016).

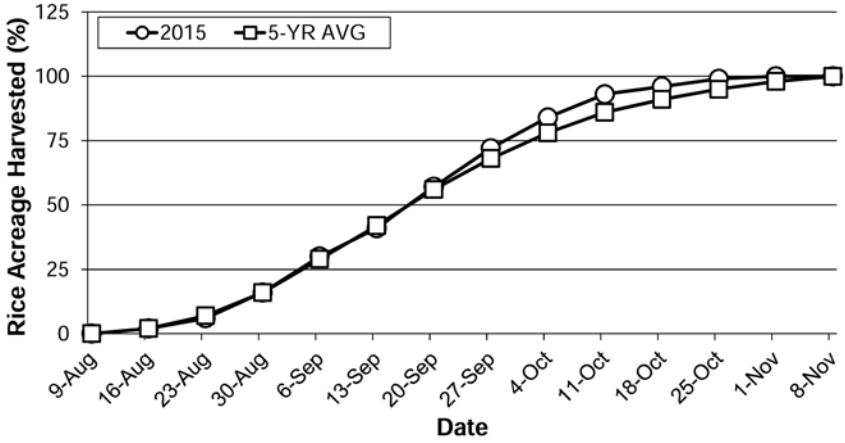

Fig. 2. Arkansas rice harvest progress during 2015 compared to the five-year state average (USDA-NASS, 2016).

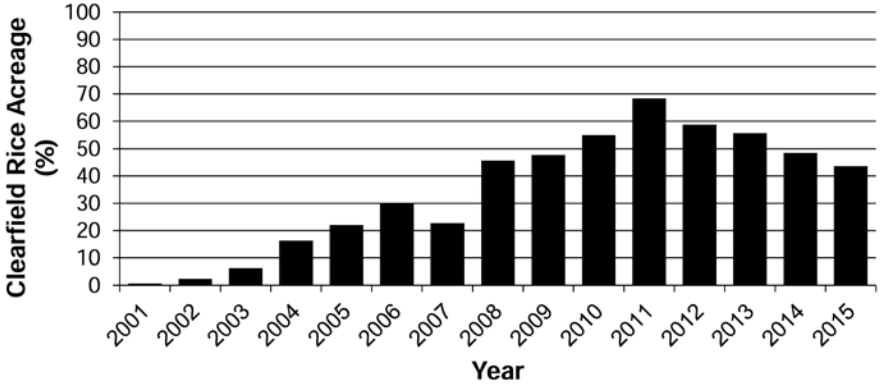

Fig. 3. Percentage of rice planted in Arkansas to Clearfield rice cultivars between 2001 and 2015.

2015 Rice Research Verification Program

R. Baker[1], R. Mazzanti[2], J.T. Hardke[2], K.B. Watkins[3], and R. Mane[4]

ABSTRACT

The 2015 Rice Research Verification Program (RRVP) was conducted on 16 commercial rice fields across Arkansas. Counties participating in the program included Arkansas, Ashley, Chicot, Clay, Cross, Desha, Independence, Lawrence, Lee, Lonoke, Mississippi, Monroe, Phillips, Randolph, St. Francis, and White counties for a total of 1013 acres. Grain yield in the 2015 RRVP averaged 176 bu/acre ranging from 119 to 237 bu/acre. The 2015 RRVP average yield was 13 bu/acre greater than the estimated Arkansas state average of 163 bu/acre. The highest yielding field was in Randolph County with a grain yield of 237 bu/acre. The lowest yielding field was in Lee County and produced 119 bu/acre. Milling quality in the RRVP was comparable with milling from the Arkansas Rice Performance Trials and averaged 58/72 (head rice/total white 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, 5) incorporate data from RRVP into CES educational programs at the county and state level. Since 1983, the RRVP has been conducted on 431 commercial rice fields in 33 rice-producing counties in Arkansas.

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The program has typically averaged 20 bu/acre better than the state average yield. 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 needed 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 2015 included Arkansas, Ashley, Chicot, Clay, Cross, Desha, Independence, Lawrence, Lee, Lonoke, Mississippi, Monroe, Phillips, Randolph, St. Francis, and White Counties. The sixteen rice fields totaled 1013 acres enrolled in the program. Eight different cultivars were seeded (CL151, CL271, RiceTec CLXL745, Jupiter, LaKast, Mermentua, Roy J, and RiceTec XL753) and CES recommendations were used to manage the RRVP fields. Agronomic and pest management decisions were based on field history, soil test results, 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, grain yield, milling yield, and grain quality.

RESULTS AND DISCUSSION

Yield

The average RRVP yield was 176 bu/acre with a range of 119 to 237 bu/acre (Table 1). All grain yields of RRVP fields are reported in dry, 12% moisture, bushels. The RRVP average was 13 bu/acre more than the estimated State yield of 163 bu/acre. This difference has been observed many times since the program began and can be attributed in part to intensive management practices and utilization of CES recommendations. The Randolph County field, seeded with RiceTec XL753, was the highest yielding RRVP field at 237 bu/acre. Eight of the sixteen fields enrolled in the program exceeded 170 bu/acre. Lee County had the lowest yielding field with LaKast producing 119 bu/acre.

Milling data was recorded on all of the RRVP fields. The average milling yield for the sixteen fields was 57/72 (head rice/total white rice) with the highest milling yield of 66/74 with Roy J in Cross County (Table 1). The lowest milling yield was 50/72 with RiceTec CLXL745 in Chicot County. The milling yield of 55/70 is considered the standard used by the rice milling industry.

Planting and Emergence

Planting began with Arkansas County on 30 March and ended with White County planted 7 May (Table 1). Two of the verification fields were planted in March, twelve in April, and two in May. An average of 74 lb seed/acre was planted for pure-line varieties and 25 lb seed/acre 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 19 plants/ft^2 for pure-line varieties and 7 plants/ft^2 for hybrids. The seeding rates in some fields were higher than average due to planting method, soil texture, and planting date. Broadcast seeding and clay soils generally require an elevated seeding rate to achieve desired plant populations.

Fertilization

The Nitrogen Soil Test for Rice (N-STaR) was utilized on 9 of 16 RRVP fields. The difficult early-season conditions of 2015 required, for some fields, a deviation from the N-STaR recommendations. Nitrogen recommendations were based on a combination of factors including soil texture, previous crop, and cultivar requirements (Table 2). Nitrogen rates can appear high in some fields with a clay soil texture and when rice was the previous crop. These factors increase the nitrogen requirements compared to a silt loam soil where soybeans were the previous crop. The Lee County field received ammonium sulfate (21-0-0-24) at the 2- to 3-lf stage as a management tool to increase plant growth and shorten the time required to get the rice to flood stage. The White County field received a poultry litter application in the fall to improve soil conditions following land leveling.

Phosphorus, potassium, and zinc fertilizer were applied based on soil-test analysis recommendations (Table 2). Phosphorus was applied preplant to Arkansas, Ashley, Chicot, Cross, Independence, Lawrence, Lee, Randolph, St. Francis, and White County fields. Potassium was applied to Arkansas, Ashley, Clay, Cross, Desha, Independence, Lawrence, Lee, Randolph, St. Francis, and White Counties. Zinc was applied as a preplant fertilizer to fields in Cross, Desha, Independence, Lawrence, Lee, and White Counties, while zinc seed treatment was used with hybrid rice cultivars at a rate of 0.5 lb zinc/60 lb seed. The average cost of fertilizer across all fields was $120.46.

Weed Control

Command was utilized in 13 of the 16 fields for early-season grass control (Table 3). Facet was applied in 10 of 16 fields either pre-emergence or early post-emergence.

Four fields (Ashley, Chicot, Clay, and Lonoke Counties) were seeded in Clearfield cultivars (Table 1). Only the Mississippi County field did not require a post-emergence herbicide application for grass weed control (Table 3).

Disease Control

Foliar fungicides were applied to 2 of the 16 fields in 2015 for management of sheath blight and prevention of kernel smut (Table 4). Fungicide rates were determined based on cultivar, growth stage, climate, disease incidence/severity, and disease history. Fourteen fields had a seed treatment containing a fungicide.

Insect Control

Nine fields (Arkansas, Ashley, Chicot, Cross, Desha, Independence, Lee, Mississippi, and Phillips Counties) were treated with a foliar insecticide application for rice stink bug in 2015 (Table 4). Thirteen fields received an insecticide seed treatment in the form of CruiserMaxx Rice.

Irrigation

Well water was used to irrigate 10 of the 16 fields in the 2015 RRVP while 6 fields were irrigated with surface water. Three fields (Ashley, Chicot, and Lonoke Counties) were zero-grade. Ten fields used Multiple Inlet Rice Irrigation (MIRI) either by utilizing irrigating tubing or by having multiple risers or water sources. Typically, a 25% reduction in water use is observed when using MIRI. Flow meters were used in 14 of the fields to record water usage throughout the growing season (Table 5). In fields where flow meters were not utilized, the average across all irrigation methods of 30 acre-inches was used. The difference in water used was due in part to rainfall amounts which ranged from 6.2 to 26.1 inches.

Economic Analysis

This section provides information on production costs and returns for the 2015 RRVP (Tables 6 and 7). 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 2015 Crop Enterprise Budgets published by the CES 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 for each RRVP field 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 $411.49/acre for Lonoke County to $749.15 for White County, while operating costs per bushel ranged from $2.24/bu for Mississippi County to $4.62/bu for White County. Total costs per acre (operating plus fixed) ranged from $526.87/acre for Lonoke County to $846.50/acre for Chicot County, and total costs per bushel ranged from $2.76/bu for Mississippi County to $5.35/bu for Lee County. The average return above operating costs for the 16 fields was $350.18/acre and ranged from $38.29/acre for Lee County to $680.11/acre for Mississippi County (Tables 6 and 7). The average return above total costs for the 16 fields was $249.20/acre and ranged from -$48.22/acre for Lee County to $579.75/acre for Mississippi County.

A summary of yield, rice price, revenues, and costs by cost type for each RRVP field are presented in Table 7. The average rice yield for the 2015 RRVP was 176 bu/acre but ranged from 119 bu/acre for Lee County to 237 bu/acre for Randolph County (Table 1). An Arkansas average long-grain cash price of $4.92/bu was estimated using USDA, National Agricultural Statistics Service (USDA-NASS, 2016) U.S. long-grain price data for the months of August through October. The RRVP had four fields planted to the medium-grain cultivar Jupiter. The average medium-grain price contracted in Arkansas was estimated to be $5.68/bu and represented the average long-grain price plus an average medium-grain premium of $0.76/bu. The average medium-grain premium was estimated based on the average difference in Arkansas milled rice value between medium- and long-grain rice obtained from the Arkansas Weekly Grain Review for the period 3 August through 2 November, converted to a rough rice equivalent. A premium or discount was given to each field based on the milling yield observed for each field and standard milling yields of 55/70 for long-grain rice and 58/69 for medium-grain rice. Broken rice was assumed to have 70% 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 $4.83/bu in Ashley County to $5.38/bu in Cross County (Table 7). The medium-grain price adjusted for milling yield varied from $5.59/bu for Desha County to $5.84/bu for Independence County.

The average operating cost for the 16 RRVP fields was $571.43/acre (Table 7). Fertilizer and nutrients accounted for the largest share of operating costs on average (21.1%) followed by post-harvest expenses (20.4%), seed (15.0%), and chemicals (13.3%). Although seed's share of operating expenses was 15.0% across the 16 fields, its average cost and share of operating costs varied depending on whether a Clearfield hybrid was used ($195.36/acre; 27.9% of operating expenses), a non-Clearfield hybrid was used ($130.56/acre; 18.6% of operating expenses), a Clearfield non-hybrid (pure-line) variety was used ($95.62/acre; 19.7% of operating expenses) or a non-Clearfield non-hybrid (pure-line) variety was used ($44.45/acre; 8.6% of operating expenses). Table 8 provides select variable input costs for each field and includes rice type; seed, fertilizer, diesel fuel, and irrigation costs; as well as chemical costs for herbicides, insecticides, and fungicides.

Field Summaries

The 48-acre Arkansas County field was located southeast of Stuttgart on a Stuttgart and Dewitt silt loam soil. The previous crop was soybean. Conventional tillage practices were used for field preparation and a preplant fertilizer based on soil test results was applied at a rate of 0-30-90-10 (lb/acre N-P_2O_5-K_2O-Zn). RiceTec hybrid XL753 was drill-seeded on 30 March at 22 lb/acre. CruiserMaxx Rice seed treatment was used in addition to the company's standard seed treatment. Rice emerged on 13 April with a stand density of 6.4 plants/ft^2. Glyphosate herbicide was used as a burndown on 4 April. Command and League were applied as pre-emergence herbicides on 13 April. Excellent residual herbicide activity was observed for 30 days. Facet and Permit Plus herbicides were applied 15 May and provided post-emergence control of dayflower and nutsedge. Using the N-STaR recommendation, nitrogen in the form of urea plus an approved N-(n-butyl) thiophosphoric triamide (NBPT) product was applied preflood at a rate of 235 lb/acre on 15 May. Multiple-inlet rice irrigation was utilized to achieve a more efficient permanent flood. On 7 July urea at 70 lb/acre was applied at the late-boot stage. The field was clean throughout the year and a deep flood was maintained. No fungicides were needed for disease but rice stink bugs reached threshold levels and were treated with Karate insecticide on 14 July. The field was harvested on 8 August with a yield of 213 bu/acre[5]. The average harvest moisture was 18% and the milling yield was 59/71. This was the second-highest yield in the 2015 RRVP. Irrigation water use totaled 31.9 acre-inches with rainfall amounts totaling 13.25 inches.

The zero-grade, 79-acre Ashley County field was located east of Montrose on a Grubbs silt loam and Jackport silty clay loam soil. Preplant fertilizer was applied at a rate of 0-40-60 (lb/acre N-P_2O_5-K_2O). The previous crop was soybean and conventional tillage practices were utilized in the spring. RiceTec hybrid CL XL745 was drill-seeded at 23 lb/acre on 8 April. The seed was treated with CruiserMaxx Rice seed treatment in addition to the company's standard seed treatment. A pre-emergence application of Command herbicide was made on 11 April. Rice emergence was observed on 19 April with 7.6

[5] The yield for this and all other RRVP fields is reported in dry, 12% moisture, bushels.

plants/ft^2. Ammonium sulfate was applied on 8 May as a starter fertilizer at 100 lb/acre. On 26 May Clearpath and Permit Plus herbicides were applied. Nitrogen in the form of urea plus an approved NBPT product was applied on 14 May at 330 lb/acre according to N-STaR recommendations. The late boot nitrogen application of urea at 70 lb/acre was applied on 17 July. No fungicides were necessary since disease never reached threshold levels. Stink bugs reached threshold level and Lambda-Cy insecticide was applied on 31 July. The field was harvested on 29 August yielding 166 bu/acre. The milling yield was 53/69 and the average harvest moisture was 18%. The irrigation water use totaled 28.4 acre-inches and rainfall for the growing season was 19.75 inches.

The 69-acre zero-grade Chicot County field was located north of Lake Village on a Perry clay soil. On 3 April, RiceTec hybrid CL XL745, treated with CruiserMaxx Rice seed treatment in addition to the company's standard seed treatment, was drill-seeded at 33 lb/acre. Preplant fertilizer was applied on 5 April at the rate of 0-69-0 (lb/acre N-P_2O_5-K_2O) according to soil-test recommendations. Glyphosate, Command, and League were applied on 4 April as burndown and pre-emergence herbicides. Continuous rainfall on a weekly basis provided residual weed control for 58 days. Field emergence was recorded on 30 April with a stand density of 2.5 plants/ft^2 that eventually increased to 3.5 plants/ft^2. On 8 June, Ricestar HT herbicide was applied post-emergence for sprangletop escapes. Based on N-STaR recommendations, nitrogen in the form of urea was applied preflood at 250 lb/acre on 8 May. Late boot urea fertilizer at 70 lb/acre was applied on 14 June. Rice stink bugs reached treatment levels and Lambda-Cy insecticide was applied on 16 July. The field was harvested 14 August with a yield of 196 bu/acre, milling yield of 50/72, and an average harvest moisture of 12%. The grower was pleased with the yield considering the low stand count and unfavorable weather in April and May. Irrigation water used totaled 30.0 acre-inches. Rainfall amounts were 6.2 inches for the season.

The precision-graded Clay County field was located 7.5 miles southwest of Corning on a Jackport silty clay loam soil. The field was 78 acres and the previous crop grown was soybean. In late April, conventional tillage practices were used for field preparation and a preplant fertilizer based on soil-test analysis was applied at a rate of 0-0-60 (lb/acre N-P_2O_5-K_2O). On 29 April, the medium-grain variety CL271 with CruiserMaxx Rice seed treatment was drill-seeded at a rate of 65 lb/acre. Rice emergence was observed on 12 May and consisted of 13.4 plants/ft^2. Command was applied as a pre-emergence herbicide plus glyphosate as a burndown herbicide prior to crop emergence. This was followed by a post-emergence application of Clearpath followed later by Newpath. Excellent pre- and post-emergence control of weeds was achieved. Using the N-STaR recommendation, a single preflood N application was made with the intention of excluding a midseason N application. Urea plus an approved NBPT product was applied at a rate of 207 lb/acre on 27 June. However, nitrogen loss prior to flood-up made it necessary to apply midseason N to correct the problem. Urea at a rate of 100 lb/acre was applied on 16 July. Once the permanent flood was established, flood levels were maintained well throughout the season. Although sheath blight lesions were found in the field, they remained low on the plant and cool nighttime temperatures helped hold

the disease well below treatment threshold levels. Continued field evaluations resulted in no treatments for sheath blight or any other disease. Rice stink bugs were present in the field but remained below treatment threshold levels and no insecticide treatments were required. On 21 September, a sodium chlorate harvest aid treatment was applied at the rate of 1 gal/acre. The rice was harvested on 24 September, yielding 202 bu/acre, an average harvest moisture of 17%, and a milling yield of 57/74. Total irrigation water use was 32.9 acre-inches and total rainfall for the season was 18.5 inches.

The traditionally contoured Cross County field was located 2.4 miles southwest of Hickory Ridge on Crowley and Hillemann silt loam soils. The field was 27 acres and the previous crop grown was soybean. Conventional tillage practices were used for spring field preparation and a preplant fertilizer based on soil-test analysis was applied at a rate of 0-40-60-2 (lb/acre N-P_2O_5-K_2O-Zn). On 8 April, the variety Roy J with CruiserMaxx Rice seed treatment was broadcast-seeded at a rate of 90 lb/acre. Rice emergence was observed on 16 April and consisted of 21 plants/ft^2. Command herbicide was applied pre-emergence followed by a post-emergence application of Facet plus propanil followed by Ricestar HT. Levees were sprayed with 2,4-D plus Grandstand. Good pre- and post-emergence control of weeds was achieved. Using the N-STaR recommendation, urea plus an approved NBPT product was applied preflood on 29 May at 174 lb/acre. Multiple-inlet rice irrigation was utilized to achieve a more efficient permanent flood. Once the permanent flood was established, flood levels were maintained well throughout the season. A midseason application of urea was made on 22 June at the rate of 100 lb/acre. No fungicide applications were required. However, rice stink bugs reached treatment level on 25 July and were treated with Karate insecticide. Rice was harvested on 12 September with a yield of 139 bu/acre. The low yield was notably similar to other fields in that part of the state, including two other RRVP fields that were in the same vulnerable stages of development during unfavorable weather conditions. Moisture at harvest was 15% and the milling yield was 66/74. Total irrigation water use was 24.4 acre-inches and total rainfall for the season was 22.8 inches.

The zero-grade, 31-acre Desha County field was located just east of Tiller on a Herbert silt loam and Perry clay soil. No tillage practices were performed from the previous rice crop. Preplant fertilizer at 0-0-90-10 (lb/acre N-P_2O_5-K_2O-Zn) was applied 30 March. The medium-grain variety Jupiter was drill-seeded at a rate of 70 lb/acre on 31 March. The seed was treated with CruiserMaxx Rice seed treatment. Glyphosate, Command, and League herbicides were applied for burndown and pre-emergence weed control on 1 April. Rice emergence was observed on 14 April with 19 plants/ft^2. A post-emergence herbicide application of Permit was made on 7 May. Nitrogen in the form of urea plus an approved NBPT product was applied preflood at 270 lb/acre according to N-STaR recommendations. Multiple-inlet rice irrigation was utilized to achieve a more efficient permanent flood. The spreader buggy application left the field streaked and on 4 May 100 lb urea/acre was applied by air to correct the problem. No midseason urea application was necessary according to GreenSeeker (Trimble Navigation Limited, Sunnyvale, Calif.) technology. Stink bugs reached threshold level and Lambda-Cy was applied 18 July. The field was harvested 2 September yielding 170 bu/acre with a

milling yield of 57/68. The average harvest moisture was 18%. The yield was slightly disappointing but characteristic of the 2015 growing season. The irrigation water use totaled 27 acre-inches and the rainfall amount for the growing season was 18.7 inches.

The precision-graded Independence County field was located 1.5 miles southwest of Oil Trough. The soil combination was a Jackport silty clay loam, Engham silt loam, and Hontas silt loam. The field was 43 acres and the previous crop grown was soybean. Conventional tillage practices were used in the fall and spring for field preparation and a preplant fertilizer based on soil-test analysis was applied at a rate of 0-46-96-0.5 (lb/acre N-P^2O^5-K^2O-Zn). On 9 April, the medium-grain variety Jupiter with CruiserMaxx Rice plus Release seed treatment was drill-seeded at a rate of 70 lb/acre. Rice emergence was observed on 21 April and consisted of 20 plants/ft^2. Command herbicide was applied pre-emergence 9 April followed on 29 May by a post-emergence application of Command plus Sharpen providing excellent pre- and post-emergence control of weeds except on the edges of the field. An additional treatment of Permit and Grasp was applied to field edges for full weed control. Using the N-STaR recommendation, a single preflood N application was made with the intention of excluding a midseason N application. Urea plus an approved NBPT product was applied at a rate of 185 lb/acre on 6 June. Unfortunately, some nitrogen loss occurred before flood-up took place making it necessary to apply midseason N to correct the problem. Urea at a rate of 100 lb/acre was applied on 27 June. Once the permanent flood was established, flood levels were maintained well throughout the season. Although sheath blight lesions were present in the field, they remained low on the plant and cool nighttime temperatures helped hold the disease well below threshold treatment levels. Continued field evaluations resulted in no treatments for sheath blight or any other disease. Rice stink bugs were found to overwhelm natural predators in the field, exceeding the threshold level for treatment. Control of the pest was accomplished with a single treatment of 2 oz/acre Karate on 31 July. No further insecticide treatments were required. The rice was harvested on 25 September yielding 196 bu/acre with a harvest moisture of 18%. The milling yield was 55/73. Total irrigation water use was 35.2 acre-inches and total rainfall for the growing season was 26.1 inches.

The precision-graded Lawrence County field was located north of Alicia on a Dubbs silt loam soil. The field was 50 acres and the previous crop grown was soybean. Conventional tillage practices were used for field preparation in the spring. A preplant fertilizer based on soil-test analysis was applied on 24 April at the recommended rate of 0-40-48-8-4 (lb/acre N-P_2O_5-K_2O-Zn-S). On 27 April, the variety Mermentau was drill-seeded at a rate of 80 lb/acre. Rice emergence was observed on 9 May and consisted of 25 plants/ft^2. Command pre-emergence herbicide plus glyphosate as a burndown herbicide were applied on 28 April. On 30 May a post-emergence application was made of Grasp Xtra plus Command to extend its residual activity. Good pre- and post-emergence control of weeds was provided. Using the N-STaR recommendation, urea plus an approved NBPT product at the rate of 250 lb/acre was applied preflood on 12 June followed by a normal midseason application of 100 lb of urea/acre on 29 June. Multiple-inlet irrigation was utilized to achieve a more efficient permanent flood.

Once the permanent flood was established, flood levels were maintained sufficiently throughout the season but not without some difficulty due to the permeable nature of portions of the field. Lesions caused by sheath blight fungus reached treatment level. An application of Quadris fungicide was made on 29 July and no further fungicide applications were required. Rice stink bugs were present in the field but remained below threshold levels the entire season and no insecticide treatments were required. Harvest began on 22 September and the yield average was 163 bu/acre, with a harvest moisture of 18%, and a milling yield of 64/73. Total irrigation water use was 82.0 acre-inches, reflecting highly permeable areas of the field. Total rainfall for the season was 18.7 inches.

The 54-acre Lee County field was located just east of Moro on a Calloway and Henry silt loam soil. Soybean was the previous crop grown on the field and no tillage practices were performed on the contour field. A preplant fertilizer blend of 21-40-75-10-1 (lb/acre N-P_2O_5-K_2O-Zn-S) was applied according to the soil sample analysis. On 8 April the variety LaKast, treated with CruiserMaxx Rice seed treatment and zinc, was broadcast at a rate of 75 lb/acre. Sharpen, glyphosate, and Command were applied on 8 April as burndown and pre-emergence herbicides. Ammonium sulfate was applied at 100 lb/acre as a starter fertilizer. Emergence was observed on 28 April with 12 plants/ft^2. Facet and Permit were applied on 6 May as post-emergence herbicides. Based on N-STaR recommendations, nitrogen in the form of urea plus an approved NBPT product was applied at 240 lb/acre on 26 May. A minimal flood was maintained throughout the growing season with MIRI. Using GreenSeeker technology, midseason urea fertilizer was applied 16 June on the south half of the field at 100 lb/acre. Plant nitrogen on the north half of the field was sufficient without applying midseason urea. Stink bugs reached threshold levels and Lambda-Cy insecticide was applied on 28 July. The field was harvested on 2 September yielding 119 bu/acre with a milling yield of 51/72. Broadcast planting, low stand counts, and excessive cloudiness during early season to midseason all contributed to a decreased yield. The average harvest moisture was 15%. The irrigation water use totaled 33.9 acre-inches and the season-long rainfall total was 15.8 inches.

The 36-acre zero-grade Lonoke County field was located south of England on a Perry silty clay soil. No tillage practices were performed on the field from the previous rice crop. Based on soil-test analysis, no preplant fertilizer was needed. The variety CL151, treated with CruiserMaxx Rice seed treatment and zinc, was drilled-seeded at 65 lb/acre on 11 April. Glyphosate, Command, and League herbicides were applied 25 April. Rice emergence was observed on 26 April with 16 plants/ft^2. Due to continual rainfall, residual herbicide activity was observed for 35 days. On 1 June, Command and Ricestar HT herbicides were applied for continued grass control. Nitrogen in the form of urea plus an approved NBPT product was applied at 190 lb/acre on 19 May according to N-STaR recommendations. An adequate flood was maintained throughout the growing season. No midseason fertilizer was necessary according to GreenSeeker technology. The field was harvested on 2 September yielding 167 bu/acre with a milling yield of 59/72. For comparison, the 2014 yield in the same field with the same variety was 188 bu/acre. The 21 bu/acre difference from 2014 to 2015 was consistent with 2015 growing season results. Irrigation water use totaled 48 acre-inches and the rainfall for the growing season totaled 15 inches.

The precision-graded Mississippi County field was located 3 miles east of Dyess on a Sharkey silty clay/Sharkey-Steele complex soil. The field was 30 acres which lay fallow the previous year. Conventional tillage practices were used for field preparation in the spring. Based on soil-test analysis, no preplant fertilizer was needed. On 6 April, the medium-grain variety Jupiter was drill-seeded at a rate of 90 lb/acre. Rice emergence was observed on 15 April and consisted of 16 plants/ft^2. Prowl H_2O herbicide plus Roundup WeatherMAX plus Facet L was applied pre-emergence on 6 April and provided excellent control of weeds; no post-emergence herbicide application was needed. Urea plus an approved NBPT product at a rate of 250 lb/acre was applied preflood on 24 May followed by a split midseason application of urea at 150 lb/acre (75 lb on 15 June followed by 75 lb on 22 June). It should be noted that applying midseason N in a split application is no longer the preferred recommendation by the CES. Proper preflood N fertilization followed by a single midseason N application has been found to be the most cost effective and efficient means of split N fertilization in rice. Once the permanent flood was established, flood levels were maintained sufficiently throughout the season. Although sheath blight lesions were present in the field, they remained low on the plant and cool nighttime temperatures helped hold the disease well below threshold treatment levels. Continued field evaluations resulted in no treatments for sheath blight or any other disease. Rice stink bugs exceeded the threshold level for treatment and Karate was applied for control on 27 July. No further insecticide treatments were required. Harvest began on 1 September and the yield averaged 191 bu/acre with a harvest moisture of 21%. The milling yield was excellent at 65/68. Total irrigation water use was 21 acre-inches and total rainfall for the season was 22.3 inches.

The precision-graded, 60-acre Monroe County field was located east of Clarendon on a Grubbs silt loam and Jackport silty clay loam soil. Conventional tillage practices were used for field preparation in the spring and soybean was the previous crop. Based on soil-test analysis, no preplant fertilizer was needed. The medium-grain variety Jupiter, treated with CruiserMaxx Rice seed treatment and Release, was drill-seeded at 72 lb/acre on 16 April. Emergence was observed on 28 April at 15 plants/ft^2. Glyphosate, Command, and League herbicides were applied on 17 April giving 25 days residual control. Facet and RiceBeaux were applied 12 May as post-emergence herbicides. Nitrogen fertilizer in the form of urea plus an approved NBPT product was applied 12 June at 300 lb/acre according to N-STaR. An adequate permanent flood was maintained throughout the growing season using MIRI. No fungicide or insecticide applications were necessary due to careful scouting and no midseason nitrogen was necessary according to GreenSeeker technology. The field was harvested 24 September with a grain yield of 184 bu/acre and a milling yield of 57/69. The grower was very pleased stating the yield was 20 to 24 bu/acre better than his other two Jupiter fields yet with only a fraction of the input costs. Those input cost savings included lower chemical cost from the absence of fungicide and insecticide applications and no midseason nitrogen application. Irrigation water use totaled 15.8 acre-inches and rainfall amounts totaled 14.7 inches.

The contoured 47-acre Phillips County field was located southeast of Marvell on a Calloway silt loam soil. Conventional tillage was used after the previous soybean

crop. Based on soil-test analysis, no preplant fertilizer was needed. The variety LaKast was treated with CruiserMaxx Rice seed treatment plus zinc and was drill-seeded at 72 lb/acre on 17 April. Emergence was observed on 24 April at 16 plants/ft^2. No pre-emergence herbicides were able to be applied at planting, but Facet, RiceBeaux, and Permit herbicides were applied post-emergence on 14 May. Nitrogen in the form of urea plus an approved NBPT product was applied on 25 May at 250 lb/acre. Stink bugs reached threshold levels and Karate insecticide was applied 30 July. Multiple-inlet rice irrigation was utilized to achieve a more efficient permanent flood. No midseason nitrogen was needed according to GreenSeeker technology. The field was harvested on 7 September with a yield of 160 bu/acre with a milling yield of 52/71. Again, the yield was consistent for the 2015 growing season. The irrigation amount was 30 acre-inches and the rainfall amount was 17.8 inches.

The precision-graded Randolph County field was located 2.5 miles northeast of Pocahontas on Amagon and Dundee silt loam soils. The field was 235 acres and the previous crop grown was soybean. Spring conventional tillage practices were used for field preparation and a preplant fertilizer based on soil-test analysis was applied at a rate of 0-46-120 (lb/acre N-P_2O_5-K_2O). On 6 May, RiceTec hybrid XL753 with CruiserMaxx Rice seed treatment, in addition to the company's standard seed treatment, was drill-seeded at a rate of 22 lb/acre. Rice emergence was observed on 15 May and consisted of 5.7 plants/ft^2. Command herbicide was applied pre-emergence on 7 May followed on 5 June by a post-emergence application of Prowl H_2O plus Grasp followed on 30 June by a post-flood application of Ricestar HT providing excellent pre- and post-emergence control of weeds. Using the N-STaR recommendation, urea plus an approved NBPT product was applied preflood at a rate of 217 lb/acre on 13 June. Multiple-inlet irrigation was utilized to achieve a more efficient permanent flood. Even so, due to the very large size of the field there was an extended flood-up period. This delay, combined with weather conditions, resulted in nitrogen loss ultimately requiring additional nitrogen to correct the problem. Urea at a rate of 100 lb/acre was applied on 1 July. The normal 65 lb/acre of urea at late boot for straw strength was also applied on 27 July. Once the permanent flood was established, flood levels were maintained well throughout the season. Although sheath blight lesions were present in the field, they remained low on the plant and cool nighttime temperatures helped hold the disease below threshold treatment levels. However, a preventative treatment for smut disease was applied using Quilt Xcel. Rice stink bugs were present in the field but remained below treatment levels. The rice was harvested on 6 October, yielding 237 bu/acre, the highest RRVP yield in 2015. Moisture at harvest was 14.3% and the milling yield was 53/71. Total irrigation water use was 28.4 acre-inches and total rainfall for the season was 19.9 inches.

The traditionally contoured St. Francis County field was located 2.5 miles southwest of Palestine and consisted of Henry, Calloway, and Loring silt loam soils. The field was 84 acres and the previous crop grown on the field was soybean. Conventional tillage practices were used in the fall for field preparation and a preplant fertilizer based on soil-test analysis was applied at a rate of 0-47-77 (lb/acre N-P_2O_5-K_2O). On 6 April, the variety LaKast with Apron XL LS seed treatment was drill-seeded at a rate of 70 lb/acre. Rice emergence was observed on 15 April and consisted of 26 plants/ft^2.

Sharpen plus glyphosate were applied in early spring as a burndown treatment. Command, glyphosate, and League were applied pre-emergence on 9 April followed on 27 April by a post-emergence application of Facet plus Sharpen. An additional application of Sharpen was used to control weed escapes on levees. Good pre- and post-emergence control of weeds was achieved. Urea plus an approved NBPT product was applied preflood on 29 May at a rate of 272 lb/acre. Multiple-inlet rice irrigation was used; however, permanent flood levels were difficult to establish and maintain due to a failing older well. A new well was drilled midseason providing much improved flood control. A midseason application of urea was made at the rate of 100 lb/acre on 20 June. Based on field evaluations and established pest threshold treatment levels, no fungicide or insecticide applications were required. The rice was harvested on 31 August yielding 143 bu/acre with a harvest moisture of 15%, and a milling yield of 62/72. Total irrigation water use was 37 acre-inches and total rainfall for the season was 15.7 inches.

The fresh-cut, precision-graded White County field was located 1.5 miles east of Kensett on Calloway and Immanuel silt loam soils. The field was 42 acres and the previous crop grown was soybean. A fall application of poultry litter at a rate of 1.5 tons/acre was made to improve the fresh-cut soil conditions. Spring conventional tillage practices were used for field preparation and a preplant fertilizer based on soil-test analysis was applied at a rate of 0-30-90-10 (lb/acre N-P_2O_5-K_2O-Zn). On 7 May, RiceTec hybrid XL753 with CruiserMaxx Rice seed treatment, in addition to the company's standard seed treatment, was drill-seeded at a rate of 24 lb/acre. Rice emergence was observed on 15 May and consisted of 11 plants/ft^2. Prowl H_2O herbicide was applied pre-emergence followed by a post-emergence application of Broadhead plus Facet plus Londax, providing excellent pre- and post-emergence control of weeds. Using the N-STaR recommendation, urea plus an approved NBPT product was applied preflood at a rate of 295 lb/acre on 13 June. Due to weather conditions, nitrogen loss occurred on 12 acres of the field making it necessary to apply additional N to correct the problem. Urea at a rate of 100 lb/acre was applied on the affected acres on 23 June. The entire field received the normal 65 lb/acre of urea at late boot on 23 July. Once the permanent flood was established, flood levels were maintained well throughout the season using MIRI. Based on field evaluations and established pest threshold treatment levels, no fungicide or insecticide applications were required. The field was harvested on 18 September and yielded 162 bu/acre with a harvest moisture of 16%, and a milling yield of 59/76. Total irrigation water use was 11.4 acre-inches and total rainfall for the season was 18.7 inches.

SIGNIFICANCE OF FINDINGS

Data collected from the 2015 RRVP reflects the general trend of decreasing rice yields and average returns in the 2015 growing season. Analysis of this data showed that the average yield was higher in the RRVP compared to the state average and the cost of production was equal to or less than the Cooperative Extension Service-estimated rice production costs.

ACKNOWLEDGMENTS

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Table 1. Agronomic information for fields enrolled in the 2015 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/acre)	(plants/ft^2)			(bu/acre)		(%)	
Arkansas	XL753	48	Soybean	22	6	03/30/15	04/13/15	08/13/15	213	59/71	18
Ashley	CL XL745	79	Soybean	23	7	04/08/15	04/19/15	08/29/15	166	53/69	18
Chicot	CL XL745	69	Rice	33	3	04/03/15	04/30/15	08/14/15	196	50/72	12
Clay	CL271	78	Soybean	65	13	04/29/15	05/12/15	09/24/15	202	57/74	17
Cross	Roy J	27	Soybean	90	21	04/08/15	04/16/15	09/12/15	139	66/74	15
Desha	Jupiter	31	Soybean	70	19	03/31/15	04/14/15	09/22/15	170	57/68	18
Independence	Jupiter	43	Soybean	70	20	04/09/15	04/21/15	09/25/15	196	55/73	18
Lawrence	Mermentau	50	Soybean	80	25	04/27/15	05/09/15	09/22/15	163	64/73	18
Lee	LaKast	54	Soybean	75	12	04/08/15	04/28/15	09/02/15	119	51/72	15
Lonoke	CL151	36	Rice	65	16	04/11/15	04/25/15	09/02/15	167	59/72	16
Mississippi	Jupiter	30	Fallow	90	16	04/06/15	04/15/15	09/01/15	191	65/68	21
Monroe	Jupiter	60	Soybean	72	15	04/16/15	04/28/15	09/24/15	184	57/69	13
Phillips	LaKast	47	Soybean	72	16	04/17/15	04/24/15	09/07/15	160	52/71	15
Randolph	XL753	235	Soybean	22	6	05/06/15	05/15/15	10/06/15	237	53/71	14
St. Francis	LaKast	84	Soybean	70	26	04/06/15	04/15/15	08/31/15	143	62/72	15
White	XL753	42	Soybean	24	11	05/07/15	05/15/15	09/18/15	162	59/76	16
Average		64		[b]	[c]				176	58/72	16

[a] Head rice milling yield / total rice milling yield.
[b] Seeding rates averaged 74 lb/acre for conventional cultivars and 25 lb/acre for hybrid cultivars.
[c] Stand density averaged 19 plants/ft^2 for conventional cultivars and 7 plants/ft^2 for hybrid cultivars.

Table 2. Soil test results, fertilization program, and soil classification for fields enrolled in the 2015 Rice Research Verification Program.

Field location by county	pH	Soil test P[a]	Soil test K[a]	Soil test Zn[a]	Applied fertilizer: Preflood[b] N-P-K-Zn[a]	Applied fertilizer: Urea (46% N) rates applied by timing[c,d]	Applied fertilizer: Total N rate[e]	Soil classification
		---------- (lb/acre) ----------			----------(lb/acre)----------		(lb N/acre)	
Arkansas	6.3	40	145	7.5	0-30-90-0	235-0-70	140*	Stuttgart and Dewitt silt loam
Ashley	8.1	43	487	4	0-40-60-0	330-0-70	184*	Grubbs silt loam and Jackport silty clay loam
Chicot	6.9	32	788	5	0-60-0-0	250-0-70	147*	Perry clay
Clay	5.8	96	278	19.6	0-0-60-0	207-100-0	141	Jackport silty clay loam
Cross	6.2	42	194	3.8	0-40-60-2	174-100-0	126	Crowley and Hillemann silt loams
Desha	5.7	51	179	2.2	0-0-90-10	270-100-0	170	Herbert silt loam and Perry clay
Independence	6.8	24	180	4	0-46-96-.5	185-100-0	131	Jackport silty clay loam/ Engham silt loam
Lawrence	6.6	56	232	3.4	0-40-48-8	250-100-0	161*	Dubbs silt loam
Lee	7.8	32	185	3	21-40-75-10	240-100-0[f]	156*	Calloway and Henry silt loam
Lonoke	6.7	47	713	5	0-0-0-0	190-0-0	87*	Perry silty clay
Mississippi	6.9	56	844	9.6	0-0-0-0	250-150-0	184	Sharkey silty clay/Sharkey-Steele complex
Monroe	6.7	58	320	6.2	0-0-0-0	300-0-0	138*	Grubbs silt loam and Jackport silty clay loam
Phillips	6	86	375	2	0-0-0-0	250	115*	Calloway silt loam
Randolph	6	28	118	7.4	0-46-120-0	217-100-65[g]	176	Amagon/Dundee silt loams
St. Francis	7.2	52	184	8	0-47-77-0	272-100-0	171*	Henry/Calloway/Loring silt loams
White	5.8	42	178	2.6	24-129-170-10[h]	295-65-0	203	Calloway/Immanuel silt loams

[a] N = nitrogen, P = phosphorus, K = potassium, and Zn = zinc.
[b] N-P_2O_5-K_2O-Zn-S (includes seed treatments and preplant applications).
[c] Timing: preflood - midseason - boot.
[d] All preflood Urea applications utilized an approved NBPT product.
[e] Column values with an (*) were fertilized according to N-STaR recommendations.
[f] Only half of the field received a midseason N application.
[g] Not a true midseason application but a pre-midseason correction for N loss due to adverse weather conditions.
[h] Includes analysis established from 1.5 ton of chicken litter plus 0-30-90-10 fertilizer application.

Table 3. Herbicide rates and timings for fields enrolled in the 2015 Rice Research Verification Program.

Field location by county	Pre-emergence herbicide applications (trade name and product rate/acre)[a, b]	Post-emergence herbicide applications
Arkansas	Command (11 oz) + League (3.2 oz)	Facet L (32 oz) + Permit Plus (0.75 oz) + COC[c] (1 pt)
Ashley	Newpath (4 oz) + Aim (1 oz)	Clearpath (0.5 lb) + Permit Plus (0.75 oz) + COC (1 pt)
Chicot	Glyphosate (1.5 pt) + Command (24 oz) + League (3.2 oz)	Ricestar HT (24 oz) + COC (0.5 pt)
Clay	Command (12.8 oz) + glyphosate (32 oz)	Clearpath (0.5 lb) + COC (1 pt) fb Newpath (4 oz) + COC (1 pt)
Cross	Command (12.8 oz)	Facet (0.33lb) + propanil (3 qt) fb Ricestar (24 oz) fb levee treatment 2,4-D (1 qt) + Grandstand (1 pt)
Desha	Command (11 oz) + League (3.2 oz)	Permit (1 oz) + COC (1 pt)
Independence	Command (11 oz)	Command (8 oz) + Sharpen (1 oz) + COC (12.8 oz) fb spot spray application Permit (1 oz) + Grasp (2 oz) + COC (1 qt)
Lawrence	Command (12.8 oz) + glyphosate (48 oz)	Command (8 oz) + Grasp Xtra (18 oz) + COC (1 qt)
Lee	Glyphosate (32 oz) + Command (11 oz) + Sharpen (2 oz)	Facet L (32 oz) + Permit (1 oz)
Lonoke	Glyphosate (32 oz) + Command (12 oz) + League (3.2 oz)	Ricestar HT (24 oz) + Command (12 oz)
Mississippi	Prowl H_2O (2.1 oz) + Roundup WeatherMAX (22 oz) + Facet L (32 oz)	None
Monroe	Glyphosate (32 oz) + Command (11 oz) + League (3.2 oz)	RiceBeaux (4 qt) + Facet L (32 oz)
Phillips		RiceBeaux (4 qt) + Facet L (8 oz) + Permit (1 oz)
Randolph	Command herbicide (12.8 oz)	Prowl H_2O (2 oz) + Grasp (2 oz) + COC (1 qt) fb post-flood application of Ricestar HT (24 oz)
St. Francis	Early Spring Burndown: Sharpen (2 oz) + glyphosate (26 oz) fb Pre-emerge: Command (12.8 oz) + glyphosate (28 oz) + League (3.2 oz)	Facet (0.4 lb) + Sharpen (1 oz) + COC (1 pt) fb levee treatment: Sharpen (1 oz) + COC (1 pt)
White	Prowl H_2O (2.1 oz)	Broadhead (9.2 oz) + Facet (2 oz) + Londax (1 oz) + COC (12.8 oz)

[a] All rates specified are on a per-acre basis.
[b] The abbreviation 'fb' = followed by; used to separate herbicide application events.
[c] COC = crop oil concentrate.

Table 4. Seed treatments used and foliar fungicide and insecticide applications made on fields enrolled in the 2015 Rice Research Verification Program.

	Seed treatments	Foliar fungicide and insecticide treatments			
Field location by county	**Fungicide and/or Insecticide seed treatment for control of diseases and insects attacking seedling rice**	**Fungicide Applications for control of sheath blight/kernel smut/false smut**	**Fungicide applications for control of rice blast**	**Insecticide applications for control of rice water weevil**	**Insecticide applications for control of rice stink bug/chinch bug**
	(trade name and product rate/cwt seed)	**(trade name and product rate/acre)**			
Arkansas	RTST[a] + CruiserMaxx Rice (7 oz/cwt)	------	------	------	Karate (3.7 oz)
Ashley	RTST + CruiserMaxx Rice (7 oz/cwt)	------	------	------	Lambda-Cy (4 oz)
Chicot	RTST + CruiserMaxx Rice (7 oz/cwt)	------	------	------	Lambda-Cy (4 oz)
Clay	CruiserMaxx Rice (7 oz/cwt)	------	------	------	------
Cross	CruiserMaxx Rice (7 oz/cwt)	------	------	------	Karate (2 oz)
Desha	CruiserMaxx Rice (7 oz/cwt)	------	------	------	Lambda-Cy (5 oz)
Independence	CruiserMaxx Rice (7 oz/cwt)	------	------	------	Karate (2 oz)
Lawrence	------	Quadris (10 oz)	------	------	------
Lee	CruiserMaxx Rice (7 oz/cwt) + Zinc	------	------	------	Lambda-Cy (4 oz)
Lonoke	CruiserMaxx Rice (7 oz/cwt) + Zinc	------	------	------	------
Mississippi	------	------	------	------	Karate (2 oz)
Monroe	CruiserMaxx Rice (7 oz/cwt) + Release	------	------	------	------
Phillips	CruiserMaxx Rice (7 oz/cwt) + Zinc	------	------	------	Karate (2 oz)
Randolph	RTST + CruiserMaxx Rice (7 oz/cwt)	Quilt Xcel (16 oz)	------	------	------
St. Francis	Apron XL LS (0.64 oz/cwt)	------	------	------	------
White	RTST + CruiserMaxx Rice (7 oz/cwt)	------	------	------	------

[a] RTST refers to 'RiceTec Seed Treatment' and is used to define those fields whose seed was treated by RiceTec, Inc. prior to seed purchase. Seed is treated with compounds intended to enhance germination and early-season plant growth.

Table 5. Rainfall and irrigation information for fields enrolled in the 2015 Rice Research Verification Program.

Field location by county	Rainfall	Irrigation[a]	Rainfall + Irrigation
	(inches)	(acre-inches)	(inches)
Arkansas	13.3	31.9	45.2
Ashley	19.8	28.4	48.2
Chicot	6.2	30.0*	36.2
Clay	18.5	32.9	51.4
Cross	22.8	24.4	47.2
Desha	18.7	27.0	45.7
Independence	26.1	35.2	61.3
Lawrence	18.7	82.0	100.7
Lee	15.8	33.9	49.6
Lonoke	15.0	48.0	63.0
Mississippi	22.3	21.0	43.3
Monroe	14.7	15.8	30.5
Phillips	17.8	30.0*	47.8
Randolph	19.9	28.4	48.3
St. Francis	15.7	37.0	52.7
White	18.7	11.4	30.1
	17.8	32.3	50.1

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

Table 6. Operating costs, total costs, and returns for fields enrolled in the 2015 Rice Research Verification Program.

County	Operating costs		Returns above operating costs	Fixed costs	Total costs	Returns above total costs	Total costs
	Per acre	Per bushel					
	($/acre)	($/bu)	($/acre)				($/bu)
Arkansas	654.11	3.07	425.80	97.63	751.74	328.17	3.53
Ashley	670.49	4.04	131.29	80.75	751.23	50.55	4.53
Chicot	731.20	3.73	233.12	115.30	846.50	117.82	4.32
Clay	561.32	2.78	485.04	92.08	653.40	392.96	3.23
Cross	522.59	3.76	225.23	92.80	615.39	132.43	4.43
Desha	514.46	3.03	435.84	71.44	585.90	364.40	3.45
Independence	607.02	3.10	537.62	123.72	730.73	413.91	3.73
Lawrence	536.95	3.29	323.69	164.46	701.41	159.23	4.30
Lee	549.57	4.62	38.29	86.51	636.08	-48.22	5.35
Lonoke	411.49	2.46	443.55	115.38	526.87	328.17	3.15
Mississippi	427.69	2.24	680.11	100.36	528.05	579.75	2.76
Monroe	470.51	2.56	569.09	82.93	553.44	486.16	3.01
Phillips	474.40	2.97	311.20	88.17	562.57	223.03	3.52
Randolph	708.63	2.99	459.78	109.35	817.98	350.43	3.45
St. Francis	553.29	3.87	188.88	101.43	654.72	87.45	4.58
White	749.15	4.62	114.31	93.36	842.51	20.95	5.20
Average	571.43	3.32	350.18	100.98	672.41	249.20	3.91

Table 7. Summary of revenue and costs per acre for fields enrolled in the 2015 Rice Research Verification Program.

Receipts	Arkansas	Ashley	Chicot	Clay	Cross	Desha	Independence	Lawrence
Yield (bu)	213	166	196	202	139	170	196	163
Price received	5.07	4.83	4.92	5.18	5.38	5.59	5.84	5.28
Total crop revenue	**1079.91**	**801.78**	**964.32**	**1046.36**	**747.82**	**950.30**	**1144.64**	**860.64**
Operating costs								
Seed	126.72	164.76	225.96	94.06	42.30	32.90	32.90	37.60
Fertilizers and nutrients	117.17	128.52	147.39	82.83	108.71	146.29	123.10	141.23
Chemicals	73.47	88.28	77.83	69.36	98.50	55.10	76.78	76.08
Custom applications	51.45	58.10	56.00	48.28	53.18	53.90	45.95	38.50
Diesel fuel	21.56	16.56	17.42	23.45	23.47	14.45	27.25	23.13
Repairs and maintenance	31.41	26.85	36.17	29.21	28.38	23.35	36.88	46.00
Irrigation energy costs	61.63	54.87	17.36	54.25	47.18	52.34	103.11	31.30
Labor, field activities	11.99	9.42	9.08	10.47	12.21	8.53	13.48	14.06
Other inputs and fees, pre-harvest	17.38	13.00	13.95	15.39	16.43	14.80	17.52	20.90
Post-harvest costs	141.33	110.14	130.05	134.03	92.23	112.80	130.05	108.15
Total operating expenses	**654.11**	**670.49**	**731.20**	**561.32**	**522.59**	**514.46**	**607.02**	**536.95**
Returns to operating costs	**425.80**	**131.29**	**233.12**	**485.04**	**225.23**	**435.84**	**537.62**	**323.69**
Capital recovery and fixed costs	97.63	80.75	115.30	92.08	92.80	71.44	123.72	164.46
Total specified costs[a]	**751.74**	**751.23**	**846.50**	**653.40**	**615.39**	**585.90**	**730.73**	**701.41**
Returns to specified costs	**328.17**	**50.55**	**117.82**	**392.96**	**132.43**	**364.40**	**413.91**	**159.23**
Operating costs/yield unit	3.07	4.04	3.73	2.78	3.76	3.03	3.10	3.29
Total costs/yield unit	3.53	4.53	4.32	3.23	4.43	3.45	3.73	4.30

continued

Table 7. Continued.

Receipts	Lee	Lonoke	Mississippi	Monroe	Phillips	Randolph	St. Francis	White	Average
Yield (bu)	119	167	191	184	160	237	143	162	176
Price received	4.94	5.12	5.80	5.65	4.91	4.93	5.19	5.33	5.25
Total crop revenue	**587.86**	**855.04**	**1107.80**	**1039.60**	**785.60**	**1168.41**	**742.17**	**863.46**	**921.61**
Operating costs									
Seed	60.38	97.18	42.30	57.10	57.96	126.72	37.59	138.24	85.92
Fertilizers and nutrients	143.79	44.51	79.00	70.27	58.56	150.82	135.45	249.68	120.46
Chemicals	77.57	44.77	42.76	92.21	88.52	111.78	70.63	72.65	76.02
Custom applications	51.80	27.30	45.50	28.00	31.50	56.19	53.04	54.65	47.08
Diesel fuel	16.16	16.47	26.22	18.58	20.98	24.36	23.50	23.85	21.09
Repairs and maintenance	28.18	35.73	30.65	27.49	26.19	32.53	31.96	29.87	31.30
Irrigation energy costs	65.38	18.40	12.15	30.52	57.96	16.43	71.48	33.33	45.48
Labor, field activities	10.00	9.36	9.93	10.69	11.58	9.76	12.17	13.55	11.02
Other inputs and fees, pre-harvest	17.37	6.98	12.46	13.56	14.99	22.79	22.58	25.84	16.62
Post-harvest costs	78.96	110.80	126.73	122.08	106.16	157.25	94.88	107.49	116.44
Total operating costs	**549.57**	**411.49**	**427.69**	**470.51**	**474.40**	**708.63**	**553.29**	**749.15**	**571.43**
Returns to operating costs	**38.29**	**443.55**	**680.11**	**569.09**	**311.20**	**459.78**	**188.88**	**114.31**	**350.18**
Capital recovery and fixed costs	86.51	115.38	100.36	82.93	88.17	109.35	101.43	93.36	100.98
Total specified costs[a]	**636.08**	**526.87**	**528.05**	**553.44**	**562.57**	**817.98**	**654.72**	**842.51**	**672.41**
Returns to specified costs	**-48.22**	**328.17**	**579.75**	**486.16**	**223.03**	**350.43**	**87.45**	**20.95**	**249.20**
Operating costs/yield unit	4.62	2.46	2.24	2.56	2.97	2.99	3.87	4.62	3.32
Total costs/yield unit	5.35	3.15	2.76	3.01	3.52	3.45	4.58	5.20	3.91

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

Table 8. Selected variable input costs per acre for fields enrolled in the 2015 Rice Research Verification Program.

County	Rice type	Seed	Fertilizers and nutrients	Herbicides	Insecticides	Fungicides and other inputs	Diesel fuel	Irrigation energy costs
Arkansas	XL753	126.72	117.17	66.83	6.65	---	21.56	61.63
Ashley	CL XL745	164.76	128.52	83.88	4.40	---	16.56	54.87
Chicot	CL XL745	225.96	147.39	73.21	4.62	---	17.42	17.36
Clay	CL271	94.06	82.83	65.86	---	3.50	23.45	54.25
Cross	Roy J	42.30	108.71	94.91	3.59	---	23.47	47.18
Desha	Jupiter	32.90	146.29	48.54	6.57	---	14.45	52.34
Independence	Jupiter	32.90	123.10	69.69	3.59	3.50	27.25	103.11
Lawrence	Mermentau	37.60	141.23	56.68	---	19.40	23.13	31.30
Lee	LaKast	60.38	143.79	73.17	4.40	---	16.16	65.38
Lonoke	CL151	97.18	44.51	44.77	---	---	16.47	18.40
Mississippi	Jupiter	42.30	79.00	39.16	3.60	---	26.22	12.15
Monroe	Jupiter	57.10	70.27	92.21	---	---	18.58	30.52
Phillips	LaKast	57.96	58.56	84.93	3.59	---	20.98	57.96
Randolph	XL753	126.72	150.82	81.37	---	30.41	24.36	16.43
St. Francis	LaKast	37.59	135.45	70.63	---	---	23.50	71.48
White	XL753	138.24	249.68	72.65	---	---	23.85	33.33
Average	---	85.92	120.46	69.90	4.56	14.20	21.09	45.48

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

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

ABSTRACT

A precisely controlled yield trial under the most representative soil and environmental conditions is critical for rice breeders to identify the ideal genotypes for potential varietal releases. To bridge the gap between the single location, 2-replication preliminary yield trials and the multi-state 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 yield trial (AYT) of 60 entries with 3 replications was initiated in 2015. This trial is conducted at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center, (RREC), Stuttgart, Ark.; the Pine Tree Research Station, (PTRS), near Colt, Ark.; and the Northeast Research and Extension Center, (NEREC), in Keiser, Ark. 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 under small plot yield trials. Once reaching a reasonable uniformity, rice breeding lines are bulk-harvested and tested in the single location, 2-replication preliminary yield trials, which include the Clearfield Stuttgart Initial Trial (CSIT) or Conventional Stuttgart Initial Trial (SIT). Each year, about 1000 new breeding lines are tested in 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) which only accommodate about 20 entries

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from each breeder each year. Obviously, a new replicated and multi-location trial is needed to accommodate those additional breeding lines. In addition to the verification of the findings in the previous preliminary trials, the new trial will result in purer and more uniform seed stock for URRN and ARPT trials.

PROCEDURES

A total of 60 entries were tested in the 2015 AYT trial, which included 2 Louisiana experimental hybrids, 48 Arkansas experimental lines (20 Clearfield long-grain, 4 Clearfield medium-grain, 15 semi-dwarf long-grain, 8 medium-grain, and 1 aromatic long-grain line), and 10 commercial check varieties. Twenty-six of the experimental lines were also concurrently tested in 2015 URRN and/or ARPT trials. The experimental design for all three locations is a randomized complete block with three replications. Plots measuring 5 ft wide (7 rows with 8-inch row spacing) and 14 ft long were drill-seeded at 75 lb/acre rate. The soil types at the 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 NEREC, PTRS, and RREC were 4 May, 1 May, and 22 April, respectively. A single preflood application of 150 lb nitrogen (N) in the form of urea was applied to a dry soil surface at 4- to 5-lf stage, and a permanent flood was established 2 days later. At maturity, the six 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 were conducted by Riceland Foods, Inc., Stuttgart, Ark. Grain yields were calculated as bushel per acre at 12% moisture.

Data were analyzed using the General Linear Model procedure of SAS software, v. 9.2 (SAS Institute, Inc., Cary, N.C.). Analysis of variance for grain yield, milling yields, days to 50% heading, plant height, and seedling vigor were performed for each location, and a combined analysis was conducted across the three locations. The means were separated by Fisher's protected least significant difference (LSD) test at the 0.05 probability level.

RESULTS AND DISCUSSION

The average grain yield of all genotypes across 3 locations is 185 bu/acre. Among 3 locations, RREC has the highest yield of 192, followed by 190 and 172 bu/acre of NEREC and PTRS, respectively. Of the 60 entries, experimental hybrid CLH161 (15AYT011) had the highest averaged grain yield of 229 bu/acre, followed by 217, 210, and 207 bu/acre of LaKast (15AYT009), 15AR1111 (15AYT023), and Titan (15AYT014), respectively (Table 1). Milling yields are very high for all locations with the overall head rice of 67% and total rice of 72%. The average seedling vigor is 4.1

which is normal, the average days to 50% heading is 81 days, and the average plant height is 41 inches (Table 2). Lodging was observed on two Louisiana experimental hybrids (15AYT011 and 15AYT012) with the lodging incidence of 1% and 17%, respectively.

Two Clearfield long-grain lines, 15AYT015 (15AR1024) and 15AYT032 (15AR1170), had a numerically higher grain yield than the check CL111 and CL151 (Table 1), while all four Clearfield medium-grain lines, 15AYT023 (15AR1111), 15AYT016 (15AR1027), 15AYT022 (15AR1099), and 15AYT021 (15AR1096), had either a statistically or numerically higher grain yield than the check CL271. Two conventional medium-grain lines, Titan (15AYT014) and 15AYT019 (15AR1050) had a numerically higher grain yield than the commercial check Jupiter. All conventional long-grain lines yielded lower than the check LaKast which has the conventional height, however four of them (15AYT048, 15AYT051, 15AYT052, and 15AYT053) had a numerically higher grain yield than the semidwarf check Mermentau. Some of these lines were selected for purification and increase in the winter nursery in Lajas, Puerto Rico in winter 2015.

SIGNIFICANCE OF FINDINGS

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 which can only accommodate a very limited number of entries, by offering the space 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 were excluded from URRN or ARPT trials due to insufficient space.

ACKNOWLEDGMENTS

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Table 1. Grain yield of 60 semi-dwarf long- and medium-grain breeding lines and commercial checks in the advanced yield trial (AYT) conducted at Northeast Research and Extension Center (NEREC) at Keiser, Ark.; Pine Tree Research Station (PTRS), near Colt, Ark.; and Rice Research and Extension Center (RREC), Stuttgart, Ark., 2015.

Entry	Pedigree	Grain yield			
		NEREC	PTRS	RREC	Mean
		(bu/acre)			
15AYT001	CL111	199	188	205	197
15AYT002	CL151	215	170	202	195
15AYT003	CL152	172	170	197	180
15AYT004	CL163	189	174	197	187
15AYT005	CL172	183	171	197	184
15AYT006	CL271	206	162	195	187
15AYT007	Mermentau	195	176	201	191
15AYT008	Roy J	178	158	215	184
15AYT009	Lakast	225	209	218	217
15AYT010	Jupiter	215	178	189	194
15AYT011	CLH161	239	207	241	229
15AYT012	09A/R608	222	152	208	194
15AYT013	CYBT/LM1/4/WLLS/PI597049/3/RSMT//NWBT/KATY/5/9901133/JEFF	170	161	190	174
15AYT014	Titan	213	199	210	207
15AYT015	CL111/3/CCDR//9502008/LGRU	204	186	210	200
15AYT016	NPTN//BNGL/CL161	222	172	200	198
15AYT017	CPRS/KBNT//9502008-A	186	180	183	183
15AYT018	RU0902125/CL131	197	163	172	177
15AYT019	RU0501136/RU0902162	214	207	185	202
15AYT020	CL111//CCDR/0502085	205	162	166	178
15AYT021	STG07IMI-01-129/JPTR	206	188	182	192
15AYT022	BNGL/CL161/4/9502065/3/MERC//MERC/…	210	189	185	194
15AYT023	BNGL/CL161/4/9502065/3/MERC//MERC/…	225	197	208	210
15AYT024	CL111/CCDR	195	176	181	184
15AYT025	KATY/CPRS//JKSN/3/AR1188/CCDR/4/CFX-29/CCDR	186	171	197	185
15AYT026	CCDR/RU0801167	173	163	186	174

continued

Table 1. Continued.

Entry	Pedigree	Grain yield			
		NEREC	PTRS	RREC	Mean
		---------- (bu/acre) ----------			
15AYT027	CPRS/KBNT//CFX29/CCDR/3/06CFP952	157	165	190	171
15AYT028	CPRS/KBNT//WLLS/CFX18/5/9502008/3/CPRS//82CAY21/TBNT/4/CPRS//	181	167	190	179
15AYT029	RU0902174/RU0902134	173	175	197	182
15AYT030	CPRS/KBNT//WLLS/CFX18/5/9502008/3/CPRS//82CAY21/TBNT/4/CPRS//	176	168	169	171
15AYT031	RU0902125/CL131	182	166	191	180
15AYT032	CHNR/4/CPRS/9502008-A/3/CFX 29//AR1142/LA2031	185	203	209	199
15AYT033	CPRS/KBNT//9502008-A/3/TRNS/4/CPRS/KBNT//WLLS/CFX18	155	162	199	172
15AYT034	CPRS/KBNT//WLLS/CFX18/5/9502008/3/CPRS//82CAY21/TBNT/4/CPRS//	180	170	186	179
15AYT035	CYBT/LM1/4/WLLS/PI597049/3/RU0901145	176	142	173	164
15AYT036	MRMT/4/9502008//AR1188/CCDR/3/CCDR	183	164	195	181
15AYT037	EARL/4/9502065/3/BNGL//MERC/RICO	208	186	182	192
15AYT038	RU0902162/RU0801124	216	174	180	190
15AYT039	TACAURI/3/CPRS//82CAY21/TBNT/4/CFX18/5/REX	193	184	197	191
15AYT040	CHNR/4/CPRS/9502008-A/3/CFX 29//AR1142/LA2031	179	165	191	178
15AYT041	CL181/CL111	186	136	138	153
15AYT042	CPRS/KBNT//WLLS/CFX18/3/CHNR	183	163	183	176
15AYT043	TACAURI/3/CPRS//82CAY21/TBNT/4/CFX18/5/CPRS/KBNT//WLLS/CFX18	196	162	208	188
15AYT044	CL111/3/CCDR//9502008/LGRU	177	154	177	169
15AYT045	CCDR/JEFF//CFX-18//CCDR/9770532 DH2	177	139	171	162
15AYT046	KATY/CPRS//JKSN/3/AR1188/CCDR/4/CFX-29/CCDR	182	163	171	172
15AYT047	CYBT/LM1//CHNR/3/ADAR/JDON//JEFF	168	165	186	173
15AYT048	CYBT/LM1//CHNR/3/RU0901102	209	194	190	198
15AYT049	CCDR/RU0801167	165	182	189	179
15AYT050	CCDR/RU1002183	187	177	195	186
15AYT051	FRNS/RU0902137	179	188	218	195
15AYT052	MRMT/RU0802134	186	187	204	192
15AYT053	MRMT/4/9502008//AR1188/CCDR/3/CCDR	190	177	207	191
15AYT054	CCDR//CCDR/JEFF	173	177	178	176
15AYT055	0402022/3/9502008//AR1142/MBLE/4/CTHL	168	149	210	176

continued

Table 1. Continued.

Entry	Pedigree	Grain yield			
		NEREC	PTRS	RREC	Mean
		---------- (bu/acre) ----------			
15AYT056	M207/JPTR//JPTR	185	179	191	185
15AYT057	CFFY/STG07M-07-096	203	162	154	173
15AYT058	JPTR/RU1001102	187	153	199	179
15AYT059	BNGL//ORIN/BNGL	199	184	191	191
15AYT060	L202/Leah//Toro/3/IR67016	132	127	174	144
c.v.(%)[a]		6.6	10.3	5.8	7.7
$LSD_{0.05}$		20	29	18	13

[a] c.v. = coefficient of variance; LSD = least significant difference.

Table 2. Average seedling vigor, days to 50% heading, plant height, and milling yields of 2015 advanced yield trial (AYT) conducted at Northeast Research and Extension Center (NEREC) at Keiser, Ark.; Pine Tree Research Station (PTRS), near Colt, Ark.; and Rice Research and Extension Center (RREC), Stuttgart, Ark.

Entry	Pedigree	Seedling vigor[a]	50% heading	Plant height	Milling yield[b]
			(days)	(in.)	
15AYT001	CL111	3.3	79	43	68-71
15AYT002	CL151	3.3	80	41	66-70
15AYT003	CL152	3.9	84	41	67-70
15AYT004	CL163	3.7	84	41	66-70
15AYT005	CL172	3.8	82	39	67-70
15AYT006	CL271	3.3	81	40	67-71
15AYT007	Mermentau	3.4	82	41	67-70
15AYT008	Roy J	4.1	86	42	64-69
15AYT009	Lakast	3.9	79	46	67-71
15AYT010	Jupiter	3.7	81	37	68-70
15AYT011	CLH161	4.1	79	53	65-70
15AYT012	09A/R608	3.8	87	54	60-66
15AYT013	CYBT/LM1/4/WLLS/PI597049/3/RSMT//NWBT/KATY/5/9901133/JEFF	4.7	82	40	66-71
15AYT014	Titan	4.1	77	40	66-71
15AYT015	CL111/3/CCDR//9502008/LGRU	4.2	81	41	67-71
15AYT016	NPTN//BNGL/CL161	4.2	81	40	68-71
15AYT017	CPRS/KBNT//9502008-A	4.7	83	40	69-71
15AYT018	RU0902125/CL131	3.4	82	38	68-71
15AYT019	RU0501136/RU0902162	4.0	80	37	68-72
15AYT020	CL111//CCDR/0502085	3.9	79	40	66-71
15AYT021	STG07IMI-01-129/JPTR	3.7	82	39	67-70
15AYT022	BNGL/CL161/4/9502065/3/MERC//MERC/…	4.0	79	41	67-72
15AYT023	BNGL/CL161/4/9502065/3/MERC//MERC/…	4.2	79	41	68-72
15AYT024	CL111/CCDR	4.2	80	42	66-70
15AYT025	KATY/CPRS//JKSN/3/AR1188/CCDR/4/CFX-29/CCDR	4.1	81	44	67-71
15AYT026	CCDR/RU0801167	4.8	82	43	67-71
15AYT027	CPRS/KBNT//CFX29/CCDR/3/06CFP952	4.4	82	42	66-69
15AYT028	CPRS/KBNT//WLLS/CFX18/5/9502008/3/CPRS//82CAY21/TBNT/4/CPRS//	4.7	83	40	68-71

continued

Table 2. Continued.

Entry	Pedigree	Seedling vigor[a]	50% heading	Plant height	Milling yield[b]
			(days)	(in.)	
15AYT029	RU0902174/RU0902134	4.0	83	42	69-71
15AYT030	CPRS/KBNT//WLLS/CFX18/5/9502008/3/CPRS//82CAY21/TBNT/4/CPRS//	4.0	81	38	69-72
15AYT031	RU0902125/CL131	4.1	81	40	66-69
15AYT032	CHNR/4/CPRS/9502008-A/3/CFX 29//AR1142/LA2031	4.3	84	41	68-71
15AYT033	CPRS/KBNT//9502008-A/3/TRNS/4/CPRS/KBNT//WLLS/CFX18	4.3	82	41	68-71
15AYT034	CPRS/KBNT//WLLS/CFX18/5/9502008/3/CPRS//82CAY21/TBNT/4/CPRS//	4.4	81	41	69-72
15AYT035	CYBT/LM1/4/WLLS/PI597049/3/RU0901145	4.6	82	44	67-71
15AYT036	MRMT/4/9502008//AR1188/CCDR/3/CCDR	4.2	82	42	67-70
15AYT037	EARL/4/9502065/3/BNGL//MERC/RICO	4.2	80	38	68-71
15AYT038	RU0902162/RU0801124	4.4	81	40	68-72
15AYT039	TACAURI/3/CPRS//82CAY21/TBNT/4/CFX18/5/REX	4.0	79	43	67-70
15AYT040	CHNR/4/CPRS/9502008-A/3/CFX 29//AR1142/LA2031	4.0	82	39	69-72
15AYT041	CL181/CL111	4.3	82	39	63-69
15AYT042	CPRS/KBNT//WLLS/CFX18/3/CHNR	4.2	81	42	69-72
15AYT043	TACAURI/3/CPRS//82CAY21/TBNT/4/CFX18/5/CPRS/KBNT//WLLS/CFX18	4.2	82	41	67-70
15AYT044	CL111/3/CCDR//9502008/LGRU	4.3	82	41	66-70
15AYT045	CCDR/JEFF//CFX-18//CCDR/9770532 DH2	4.1	79	40	68-70
15AYT046	KATY/CPRS//JKSN/3/AR1188/CCDR/4/CFX-29/CCDR	3.8	79	41	67-71
15AYT047	CYBT/LM1//CHNR/3/ADAR/JDON//JEFF	4.1	81	44	65-70
15AYT048	CYBT/LM1//CHNR/3/RU0901102	4.6	77	41	61-71
15AYT049	CCDR/RU0801167	4.2	79	47	66-71
15AYT050	CCDR/RU1002183	4.1	82	42	67-71
15AYT051	FRNS/RU0902137	4.2	83	43	66-70
15AYT052	MRMT/RU0802134	3.9	82	40	67-70
15AYT053	MRMT/4/9502008//AR1188/CCDR/3/CCDR	4.2	80	40	67-70
15AYT054	CCDR//CCDR/JEFF	4.1	81	40	67-71
15AYT055	0402022/3/9502008//AR1142/MBLE/4/CTHL	4.3	84	44	69-72
15AYT056	M207/JPTR//JPTR	4.1	82	40	67-70
15AYT057	CFFY/STG07M-07-096	4.4	78	42	68-71
15AYT058	JPTR/RU1001102	4.2	81	38	66-70

continued

Table 2. Continued.

Entry	Pedigree					Seedling vigor[a]	50% heading	Plant height	Milling yield[b]
							(days)	(in.)	
15AYT059	BNGL//ORIN/BNGL					4.0	80	39	67-71
15AYT060	L202/Leah//Toro/3/IR67016					4.0	80	42	63-70
c.v.(%)[c]		14.1	1.8	4.4	3-1				
$LSD_{0.05}$		0.5	1	2	2-1				

[a] A subjective rating 1 to 7 taken at emergence, 1 = excellent stand and 7 = no stand.
[b] Milling yield = % head : % total.
[c] c.v. = coefficient of variance; LSD = least significant difference.

Kompetitive Allele-Specific Polymerase Chain Reaction (KASP™) Marker-Assisted Selection for the Development of Rice Varieties

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ABSTRACT

Researchers in molecular genetics at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC) have been performing DNA marker-assisted selection (MAS) for over 15 years. The vast majority of DNA markers have been rice microsatellite or simple sequence repeat (SSR) and insertion-deletion (InDel) markers; recently wth the new equipment, a few of the more informative markers in rice, single nucleotide polymorphism (SNP) markers, are being used more often. Microsatellite and InDel markers are analyzed easily by capillary electrophoresis, but SNP markers can be particularly challenging. Cross-priming and preferential amplification have been significant problems, often rendering the data useless for interpretation. A newer technology, Kompetitive Allele-Specific Polymerase Chain Reaction (KASP™) resolves these issues. In 2015, the Molecular Genetics lab worked on five major projects for breeding involving DNA marker-assisted selection for the important traits of cooking quality, rice blast disease resistance, and Clearfield resistance. One project consisted of molecular quantitative trait loci (QTL) mapping, four other smaller projects were conducted for the breeding program and four small proprietary projects for Extension clients. The lab processed 3213 mostly bulked genomic DNA samples, generating 21,277 data points. Over 30% (6555 data points) of the total data generated for the year were derived from KASP marker analysis.

INTRODUCTION

Currently there are four rice breeding programs and cooperative extension activities which utilize the laboratory. Much of the effort over the last 15 years has been devoted to the genotypic characterization of parental lines and progeny in the areas of new long-grain and medium-grain cultivar development, hybrid rice breeding, back-

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cross populations, aromatic rice breeding, genomic mapping of specific traits, and seed purification. Single nucleotide polymorphisms (SNPs) are distributed throughout the rice genome in high abundance (Liu and Zhang, 2006; Mammadov et al., 2012; Nasu et al., 2002; and Singh et al., 2013). Liu and Zhang (2006) reported that a total of 80,127 SNP sites had been identified in the rice genome, with one SNP/154 bp found between *indica* and *japonica* rice subspecies. Seven years later, Singh et al. (2013) reported that the incidence of SNPs was found to be one SNP/140 bp in the rice genome.

These SNPs are valuable molecular markers for rapid varietal identification (Singh et al., 2013), generating high-resolution genetic maps (Liu and Zhang, 2006; Nasu et al., 2002; Singh et al., 2013), studying population structure, and discovering marker-trait relationships in association-mapping experiments (Singh et al., 2013), and for use in marker-assisted selection (MAS) in rice breeding (Liu and Zhang, 2006).

In addition to their abundance and distribution in the rice genome, SNP-based markers are gaining in popularity for genotyping due their amenability for high-throughput detection formats and platforms (Liu and Zhang, 2006; Mammadov et al., 2012; Nasu et al., 2002; Singh et al., 2013). Many different genotyping platforms and chemistries have been developed, making the analysis of SNP markers more rapid and efficient (Mammadov et al., 2012; Nasu et al., 2002). One of these platforms is Kompetitive Allele-Specific Polymerase Chain Reaction (KASP) chemistry.

Developed over 10 years ago, KASP is a Fluorescence Resonance Energy Transfer (FRET)-based endpoint detection platform capable of detecting SNP and InDel markers (LGC Genomics, Beverly, Mass.). The KASP Assay mix contains three assay-specific non-labelled oligos: two allele-specific forward primers and one common reverse primer. The allele-specific primers each have a unique tail sequence that corresponds with a quenched universal FRET cassette. One cassette is labelled with FAM™ dye and the other with HEX™ dye. The KASP Master Mix contains the universal FRET cassettes, ROX™ passive reference dye, Taq polymerase, free nucleotides and $MgCl_2$ in an optimized buffer. In the first round of PCR, the relevant allele-specific primer binds to the DNA template and elongates. This attaches the tail sequence to the newly synthesized strand. The complement of the allele specific tail is then generated during subsequent rounds of PCR. This enables the FRET cassette to bind to the DNA. The FRET cassette is no longer quenched and emits fluorescence. Bi-allelic discrimination is achieved through the competitive binding of the two allele-specific forward primers. If the genotype at a given SNP is homozygous, only one of the two possible fluorescent signals (HEX or FAM) will be generated. If the genotype is heterozygous, a mixed fluorescent signal will be generated (Green).

In 2015, materials from the RREC Rice Breeding Programs were screened with KASP markers linked to the traits of amylose (Conaway-Bormans et al., 2003; McClung et al., 2004), relative viscosity (McClung et al., 2004), gelatinization temperature (McClung et al., 2004), leaf surface texture (Fjellstrom, pers. comm.), and Clearfield herbicide resistance (Kadaru et al., 2008; Rosas et al., 2014).

The objective of this ongoing study is to apply DNA marker technology to assist with the mission of the RREC Rice Breeding Programs. The goals include (i) characterizing parental materials on a molecular level for important agronomic traits and purity, (ii)

performing DNA marker-assisted selection 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 or greenhouse-grown seedlings was collected in manila coin envelopes and kept in plastic bags on ice until being placed in storage at the molecular genetics lab. In some instances, seeds were germinated in Petri dishes to obtain leaf tissue. The leaf tissue was stored at -80 °C until sampled. Total genomic DNA was extracted from the embryo 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 and processed through a OneStep-96 PCR Inhibitor Removal system (Zymo Research Corporation, Irvine, Calif.). Eleven samples on the plate were assessed for DNA concentration and purity at the wavelengths 260 and 280 nm using an Eppendorf BioPhotometer spectrophotometer. Using the median DNA concentration of those 11 samples, the DNA of the entire 96-well plate was diluted in water to 7-8 ng/µl.

The KASP reactions were prepared by adding 5 µl of each DNA sample and 5 µl of the 2X Master Mix + 0.14 µl 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 KASP reactions were cycled in a Mastercycler Gradient S thermal cycler (Eppendorf North America, Inc., Westbury, N.Y.) using a 61-55 °C 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

Amplification was robust and the data was interpreted easily without any of the previous issues such as cross-priming (Fig. 1). The KASP marker analysis provided simple and straightforward allele calls, allowing more confidence that the interpretation of the data was accurate. Of the 6555 data points generated with KASP markers, 95% of the analysis was conducted on five major rice breeding projects for the purpose of marker-assisted selection for the development of new rice varieties. The remaining 5% of the KASP analysis was for identification purposes.

Waxy Exon 1 and *Waxy* Exon 6, two markers linked to amylose content, confirmed the previous amylose potential determined by the SSR marker RM190 in all the populations. There was a 100% correlation between the two different chemistries, giving the rice breeder a higher degree of confidence in the phenotype prediction. *Waxy* Exon 10, a marker linked to relative viscosity (RVA) of the rice grain, revealed that the all the breeding populations in the RREC program in 2015 have a weak RVA, which is typical of southern long- and medium-grain cooking quality. Only a high amylose DNA

control sample amplified the strong RVA allele. *Alk*, a marker linked to gelatinization temperature, was used to complete the grain cooking quality profile in tested populations.

Clearfield herbicide resistance trait was determined by the KASP markers for the SNPs of S653D, G654E, and A122T. The S653D SNP is the one in the vast majority of southern U.S. Clearfield varieties, but there is the possibility that materials exist in the breeding programs that have the G654E SNP in their pedigree. The A122T SNP is found in germplasm from South America, but the marker was ordered and validated to have for collaborative efforts with the scientists at Dale Bumpers National Rice Research Center.

To determine leaf surface texture, the GlabSNP KASP marker was validated for use in the program at the RREC, but has not been used for MAS at this time. Work is ongoing in obtaining a viable KASP marker for the rice blast resistance gene *Pi-ta*.

SIGNIFICANCE OF FINDINGS

Marker screening of breeding materials revealed that progress is being made in the RREC Rice Breeding Programs in reducing trait segregation and identifying promising lines to advance. Applying molecular marker technology to the Rice Breeding Programs enabled the breeders to assess the status of the populations, and eliminate those materials that are not desirable for inclusion in future rice breeding efforts, saving time, resources, and expenses.

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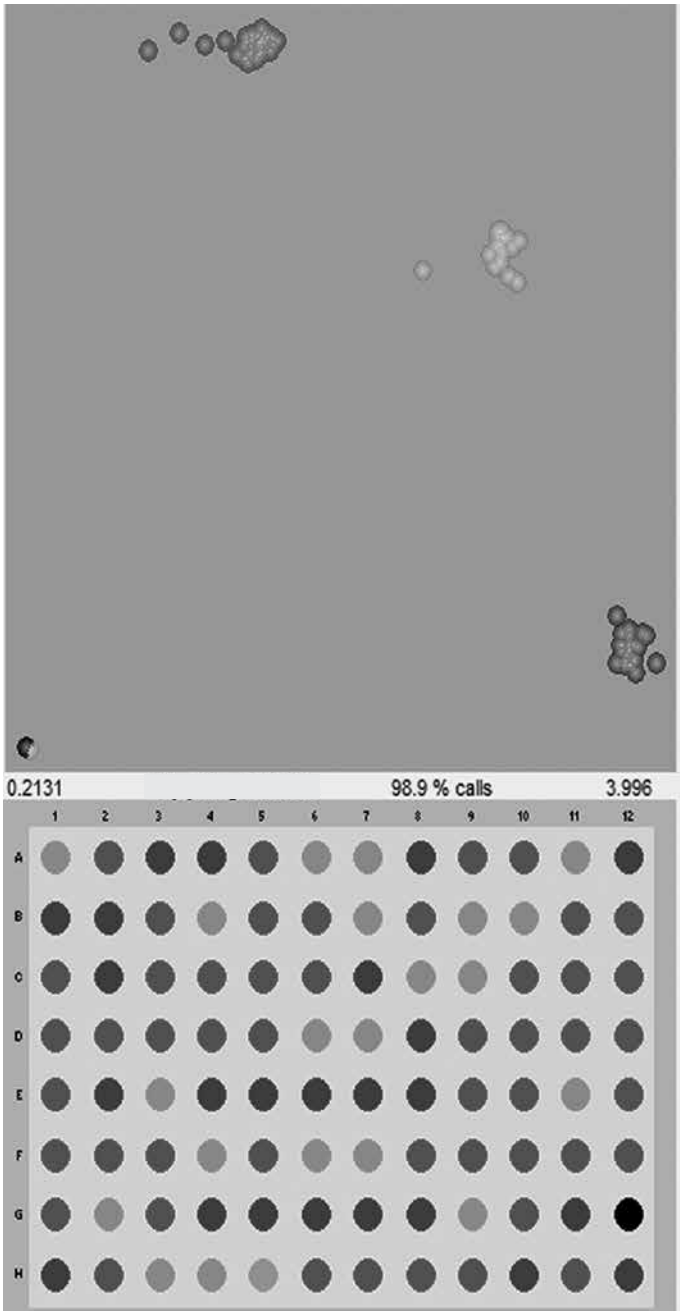

Fig. 1. KlusterCaller image of S653D Clearfield single nucleotide polymorphism (SNP).

Titan, a Very Early-Maturing, High-Yielding, and High-Quality Conventional Medium-Grain Rice Variety

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ABSTRACT

Titan (*Oryza sativa* L.) is a high-yielding, very early-maturing, and short stature medium-grain rice variety developed at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center, (RREC) near Stuttgart, Ark. It was officially approved for the formal release by the Division of Agriculture in February 2016. In yield trials conducted during 2012-2015, Titan had a 5 to 10 bu/acre yield advantage over the predominant medium-grain cultivar Jupiter. Compared with Jupiter, Titan matures about 5 days earlier, has a better resistance to leaf blast, and slightly better lodging tolerance. It also has typical southern medium-grain quality but a much larger kernel size than Jupiter. Successful development of medium-grain variety Titan certainly will provide rice producers the better option in their choice of variety and management systems for Arkansas rice production.

INTRODUCTION

Medium-grain rice is the important component of Arkansas rice. Arkansas ranks second in medium-grain rice production in the United States only behind California. During 2005-2014, an average of 0.15 million acres of medium-grain rice was grown annually, which makes up about 10% of total state rice acreage (USDA-ERS, 2015). The current predominant medium-grain variety Jupiter was released 10 years ago by Rice Research Station, Louisiana State University Agricultural Center in Crowley, La.

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Jupiter has started to show a breakdown in disease resistance especially for leaf blast. The small and short kernel size of Jupiter always has been a concern for medium-grain rice end-users other than Kellogg's. Therefore, a new conventional medium-grain variety is urgently needed to complement Jupiter.

PROCEDURES

Titan was originally selected from the cross M-206//Bengal/Lafitte/3/Jupiter made in 2006. M-206 is a Calrose-type medium-grain rice cultivar developed by California Rice Research Station at Biggs, Calif., while Bengal, Lafitte, and Jupiter are southern medium-grain rice cultivars developed by Rice Research Station, Louisiana State University Agricultural Center in Crowley (Linscombe et al., 1993; Linscombe et al., 1997; Sha et al., 2006). Jupiter is the current predominant southern medium-grain cultivar which accounts for the majority of the southern medium-grain rice acreage. Titan was introduced as a F_4 bulk of a single progeny row STG09PR-81-087 in the winter nursery in Lajas, Puerto Rico in spring 2010. It was evaluated in the preliminary yield trial (experimental designation 2010 PREL1179) in 2010, advanced to 2011 Stuttgart initial trial (SIT) as entry JG SIT2060, entered the Arkansas Rice Performance Trial (ARPT) in 2012, and the Cooperative Uniform Regional Rice Nurseries in 2013 with the experimental designation RU1301021.

RESULTS AND DISCUSSION

Titan appears to have an outstanding yield potential, good milling and grain quality, and improved lodging and blast resistance compared with the current commercial cultivar Jupiter. In 53 statewide and regional trials during 2012-2015, the average grain yield of Titan was 9054 lb/acre or 201 bu/acre compared with 8829 or 196 for Jupiter. Average milling yields (g kg^{-1} whole milled kernels : g kg^{-1} total milled rice) at 120 g kg^{-1} moisture in 45 state and regional tests from 2012-2015 were 594:691 for Titan, and 624:685 for Jupiter. Titan has a semi-dwarf plant type and is moderately resistant to lodging. It averaged 98 cm in height in yield tests across the mid-South and is slightly taller than the 95 cm of Jupiter. However, Titan matures much earlier than Jupiter. The average number of days from emergence to 50% heading is 80 compared with Jupiter at 86.

Titan has the typical medium-grain shape, and its kernels appear much larger and longer than that of Jupiter. Based on the analyses conducted by Riceland Foods, Inc. (Stuttgart, Ark.) on 12 different sets of samples collected across Arkansas during 2012-2015, the length and width (mm), length/width ratio, and kernel weight (mg) of milled whole kernels were 5.91, 2.68, 2.21, and 23.20 for Titan as compared with 5.57, 2.66, 2.09, and 21.03 for Jupiter, respectively. Average apparent amylose content of Titan is 150 g kg^{-1} compared with 156 g kg^{-1} of Jupiter. Titan also has a low gelatinization temperature of 62.8 °C similar to the 62.7 °C of Jupiter. These results indicate that Titan has typical U.S. medium-grain rice cooking characteristics.

Results from the upland rice blast nursery for leaf blast [caused by *Pyricularia grisea* (Cooke) Sacc.] indicated that Titan has moderate resistance with a rating of 1.8 on a disease scale of 0 = immune, 9 = highly susceptible, as compared with 4.8 of Jupiter. Molecular markers also confirmed that Titan possesses both blast resistant genes *Pi-z* and *Pi-ks* as compared to Jupiter's *Pi-ks* gene. In a greenhouse inoculated test, Titan was susceptible to blast races IB-1, IB-33, and IB-49, but resistant to IC-17, IE-1, IG-1, and IE1-K. Under natural infestation or inoculated evaluation, Titan appeared moderately susceptible to sheath blight (caused by *Rhizoctonia solani* Kühn) and susceptible to bacterial panicle blight (caused by *Burkholderia glumae*).

The flag leaf of Titan is longer than that of Jupiter and well above the panicle canopy at maturity. The leaves, lemma, and palea are glabrous. The spikelet is straw colored. The apiculus is red or purple at heading and the color fades as grains approach maturity. The grain is non-aromatic.

Variants observed and removed from increase fields of Titan were primarily taller and earlier. Other variants included any combination of the following: pubescent, earlier, shorter, long-grain and intermediate grain types, and gold hull. The total number of variants numbered less than 1 per 5000 plants.

About 790 hundred weight foundation seeds have been produced at the Rice Research and Extension Center, and they are available to seed rice growers for the registered seed production in 2016.

SIGNIFICANCE OF FINDINGS

Successful development of the new medium-grain rice variety Titan offers producers options in their choice of variety and management systems for Arkansas rice production. Continued utilization of new germplasm through exchange and introduction remains important for Arkansas rice improvement.

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Testing Uniform Regional Rice Nursery Varieties for Resistance to Rice Blast Disease

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ABSTRACT

In 2015, 198 Uniform Regional Rice Nursery (URRN) lines were tested with 11 reference isolates representing 9 races of the rice blast pathogen. Isolate 24 (race IG 1) and IB54 (race IB 54) were the least virulent with most rice lines being resistant to these two isolates, while 49D (race IB49), TM2 (race k), and IB33 (race IB 33) were the most virulent isolates. Nine lines were susceptible to all isolates, 17 lines were susceptible to 10 isolates, 17 lines were susceptible to 9 isolates, and more than 20% of the lines tested were very susceptible to the rice blast pathogen. However, 4 lines (RU1501030, RU1303138, RU1501050, and RU1502115) were resistant to all 11 isolates tested, 16 lines were resistant to 10 isolates, 22 lines were resistant to 9 isolates, and more than 20% lines were very resistant to the rice blast pathogen. The most resistant and most susceptible lines are listed. The results of this research will be useful to help breeders make decisions on cultivar release and to choose parental lines for their breeding programs to improve rice blast disease management.

INTRODUCTION

Rice is one of the most important staple food crops worldwide, feeding over half of the world's population. Although the United States is a relatively small rice producer growing about 3 M acres of rice annually, producing about 10 M tons of rice (accounting for <2% of world total), it is the fifth largest rice exporter, which occupies about 10% of the world rice export market. The annual value of rice in the United States is $3 billion. Rice blast disease, caused by the fungus *Magnaporthe oryzae* (anamorph: *Pyricularia oryzae*), is one of the most destructive diseases of rice, threatening the rice production in the U.S. The most economic and effective way to manage this disease is growing resistant cultivars. Research revealed that multiple races exist in the *Magnaporthe oryzae* population in the U.S., for example, race IB49 and IC-17 remain the most prevalent in Arkansas (Correll et al., 2000; Xia et al., 2000), with occasional epidemics due to "race K" type isolates (Lee et al., 2005). It is necessary to know the resistance

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spectrum of new cultivars to the current rice blast pathogen population before they are released. This study involved testing the Uniform Regional Rice Nursery (URRN) lines with 11 U.S. reference isolates of *Magnaporthe oryzae*, which are representative of the pathogen populations in Arkansas.

PROCEDURES

The 198 rice breeding lines developed by the rice breeders from Arkansas, Louisiana, Mississippi, and Texas were tested with 11 rice blast reference isolates (Table 1). The rice cultivar Francis was included in each test as the susceptible control. Rice seed were planted in plastic trays filled with river sand mixed with potting soil in the greenhouse at the University of Arkansas System Division of Agriculture's Agricultural Experiment Station, Fayetteville, Ark. Each tray was planted with 38 cells of URRN entrees and 2 cells of the susceptible control Francis. Iron sulfate was applied to the newly emerged seedlings. Then plants were fertilized with Miracle Gro All-Purpose Plant Food 20-20-20 once a week during each test. Plants were inoculated approximately 14 to 20 days after planting. Each isolate was grown on rice bran agar (RBA) (Correll et al., 2000) for approximately 7 to 10 days, then re-inoculated on new rice RBA for 7 to 10 days. Spores were collected in cool water, and adjusted to a concentration of 200,000 spores/ml per isolate. Each tray was inoculated with 50 ml of inoculum mixed with 0.02% Tween® 20 with an air compressor sprayer. After inoculation, the plants were incubated at 100% relative humidity in a mist chamber at approximately 22 °C for 24 h, and allowed to dry for 2 to 3 h before being moved to the greenhouse. The inoculated plants were incubated in the greenhouse for 6 days. On the seventh day after inoculation, the plants were scored according to a standard 0 to 9 disease rating scale (Correll et al., 1998). Lines rated 0 to 3 were considered resistant whereas those rated 4 to 9 were considered susceptible.

RESULTS AND DISCUSSION

The 198 URRN lines were tested with 11 U.S. reference isolates of *Magnaporthe oryzae*. The isolate IB33, originally recovered from rice under greenhouse conditions by F.N. Lee, and isolates 49D (race IB49) and TM2 (race k) were the most virulent isolates, with only 56, 24 and 44 lines (about 28%, 12% and 22%, respectively, of total) resistant to these three isolates. Over 70% of the lines were resistant to isolates #24 (race IG1), IB54 (race IB54), and ZN15 (race IB-1). Isolates A119 and A598 were classified as race IB49. However, 60% of the lines were resistant to isolate A119 and 35% lines resistant to A598. Again, the difference in virulence of the three IB49 (A119, A598, and 49D) isolates suggested there are differences in their virulence characteristics. The number of lines that were resistant or susceptible to each isolate was shown in Fig. 1.

Four lines (RU1501030, RU1303138, RU1501050, and RU1502115) were resistant to all tested isolates and sixteen lines (RU1402174, RU1401136, RU1302192, RU1402134, RU1401081, RU1303153, RU1402051, RU1502071, RU1203190, CL172, RU1003123, RU1502152, RU1403153, RU1401161, RU1502171, and RU1504194)

were resistant to 10 isolates; the 16 lines were only susceptible to one isolate of IB33, 49D, or TM2. A total of 22 lines were resistant to 9 isolates, and 19 lines were resistant to 8 isolates, so about 30% of the tested lines showed some resistance, which is similar to that of 2014 results. Nine lines (RU1501001, FRNS, RU1501056, RU1401070, RU1501076, RU1501093, RU1504114, RU1501182, and RU1504196) were susceptible to all isolates; Seventeen lines (RU1301084, RU1501010, RU1404122, RU1404156, RU1404157, CHNR, RU1401067, RU1404194, RU1501081, RU1501127, RU1501139, RU1501142, RU1501145, RU1504157, RU1501176, RU1501188, and RU1505001) were only resistant to one isolate. Seventeen and 25 lines were only resistant to two or 3 isolates, respectively and accounted for 35% of the total tested. The 20 most resistant and 26 most susceptible lines were listed in Table 2. The number of lines that were resistant to certain number of isolates was shown in Fig. 2. A complete examination of the entry by isolate interactions is available online at http://www.uark.edu/ua/jcorrell/data/2015URRNfinal.xls.

SIGNIFICANCE OF FINDING

The results from this study suggested that the URRN varieties had a wide range in resistance to the rice blast pathogen, which may help breeders to make decisions on the releasing of new cultivars and the choice of parental lines in their future breeding programs. The screening efforts will ultimately help the growers to select rice cultivars for the most effective disease management of rice blast disease.

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Table 1 Background information for the 11 U.S. reference isolates of *Magnaporthe oryzae* used in this study.[a]

Isolate	Vegetative compatibility group (VCG)	MGR586 group	Mating type	Race	Year	Origin
A119	US-03	C	I	IB49	1992	AR
A264	US-02	B	II	IC17	1993	AR
A598	US-01	A	I	IB49	1992	AR
#24	US-02	B	II	IG-1	1992	AR
IB33	US-04		I	IB33		AR
IB54	US-04		I	IB54		
49D	US-03	E	II	IB49	1985	AR
ZN7	US-02	B	II	IE-1	1995	TX
ZN15	US-01	A	I	IB-1	1996	TX
ZN46	US-01	A	I	IC-1	1996	FL
TM2	US-02	B	II	race K		TX

[a] The reference isolates belong to different genetic groups based on vegetative compatibility (US-01-US-08) which also correspond to different molecular fingerprint groups (MGR586 A-H).

Table 2. Disease reactions of the most resistant (20) and susceptible (26) lines tested.

Entry	Variety	A119 IB-49	A264 IC-17	A598 IB-49	24 IG-1	IB33 IB33	IB54 IB54	49D IB-49	ZN7 IE-1	ZN15 IB-1	ZN46 IC-1	TM2 Race K
30	RU1501030	0	0	0	0	0	0	1	0	0	0	1
32	RU1303138	0	0	3	0	3	0	3	0	0	3	0
50	RU1501050	2	0	3	0	0	0	3	0	0	3	2
115	RU1502115	0	0	0	0	0	0	0	0	0	0	3
8	RU1402174	0	0	3	0	3	0	3	0	0	0	6
13	RU1401136	0	0	3	0	0	0	2	0	0	0	6
28	RU1302192	1	0	3	0	3	0	8	0	1	3	0
34	RU1402134	0	0	0	0	3	0	0	0	0	0	5
41	RU1401081	0	0	0	0	0	0	1	0	0	0	6
46	RU1303153	0	0	0	0	0	0	5	0	0	0	0
51	RU1402051	0	0	0	0	0	0	0	0	0	0	8
71	RU1502071	0	0	0	0	0	0	8	0	0	0	0
78	RU1203190	1	0	3	0	0	0	8	0	0	0	3
118	CL 172	0	0	0	0	3	0	3	0	0	0	5
123	RU1003123	1	3	3	0	3	0	6	3	0	0	3
152	RU1502152	0	0	0	0	4	0	0	0	3	0	3
153	RU1403153	1	3	3	0	1	0	6	3	0	1	3
161	RU1401161	0	0	3	0	0	0	3	0	0	0	5
171	RU1502171	0	0	3	0	0	0	3	0	0	0	6
194	RU1504194	0	0	3	0	3	0	0	0	0	0	6
4	RU1301084	4	6	6	4	4	6	8	5	1	5	7
10	RU1501010	4	7	6	5	5	7	6	5	1	6	6
36	RU1404122	6	5	6	4	6	6	8	5	3	6	6
54	RU1404156	4	4	7	3	4	6	6	4	4	5	6
55	RU1404157	5	4	7	0	4	6	6	4	4	6	6
58	CHNR	4	6	6	4	4	0	6	5	4	5	6
67	RU1401067	4	7	6	4	5	6	7	5	4	1	4
74	RU1404194	4	6	6	4	6	0	6	5	4	4	8
81	RU1501081	5	1	6	5	4	6	8	5	4	6	8
94	RU1502094	5	4	0	4	5	6	8	5	4	5	8
127	RU1501127	4	5	6	0	5	6	7	6	4	6	6

continued

Table 2. Continued.

Entry	Variety	A119 IB-49	A264 IC-17	A598 IB-49	24 IG-1	IB33 IB33	IB54 IB54	49D IB-49	ZN7 IE-1	ZN15 IB-1	ZN46 IC-1	TM2 Race K
139	RU1501139	5	5	8	4	5	6	6	5	4	2	6
142	RU1501142	6	6	6	0	6	6	8	6	4	6	6
145	RU1401145	3	6	7	4	5	6	6	6	4	5	6
157	RU1504157	4	5	6	4	4	7	8	6	0	6	8
176	RU1501176	6	6	6	5	4	6	8	6	0	5	8
188	RU1501188	4	6	8	5	4	1	8	4	4	5	6
1	RU1505001	5	6	6	5	5	6	8	6	4	6	7
40	FRNS	4	6	6	4	5	6	6	5	4	6	8
56	RU1505056	6	7	7	4	5	7	7	6	4	6	6
70	RU1401070	6	6	6	4	5	6	7	5	5	6	7
76	RU1501076	5	6	6	6	6	6	7	6	5	5	7
93	RU1501093	5	4	7	4	5	5	8	5	5	5	8
114	RU1504114	4	5	6	4	4	5	8	4	5	4	6
182	RU1501182	5	6	6	5	6	4	6	6	5	6	7
196	RU1504196	5	6	6	6	6	5	6	5	5	5	6

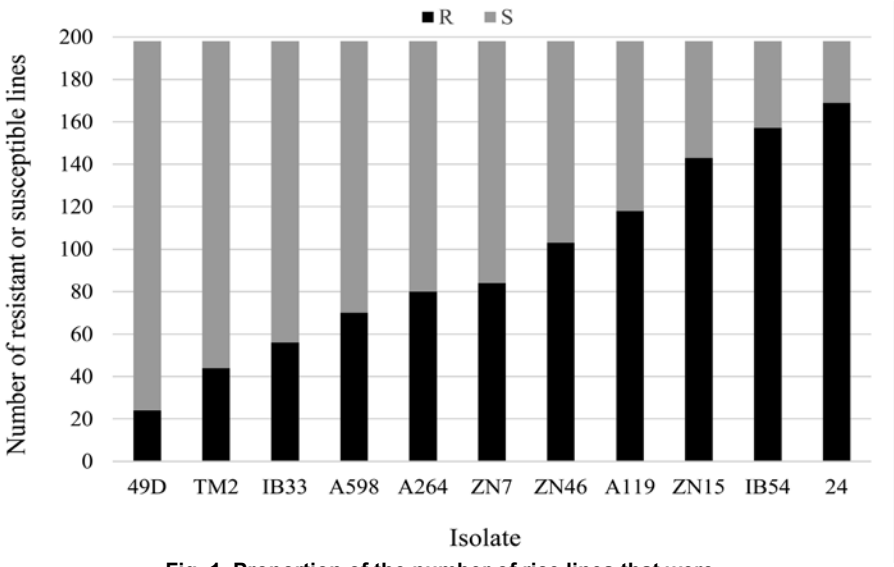

Fig. 1. Proportion of the number of rice lines that were resistant (rating scale 0 to 3, as 0 is most resistant) and susceptible (rating scales 4 to 9, as 9 is the most susceptible) to a given reference isolate.

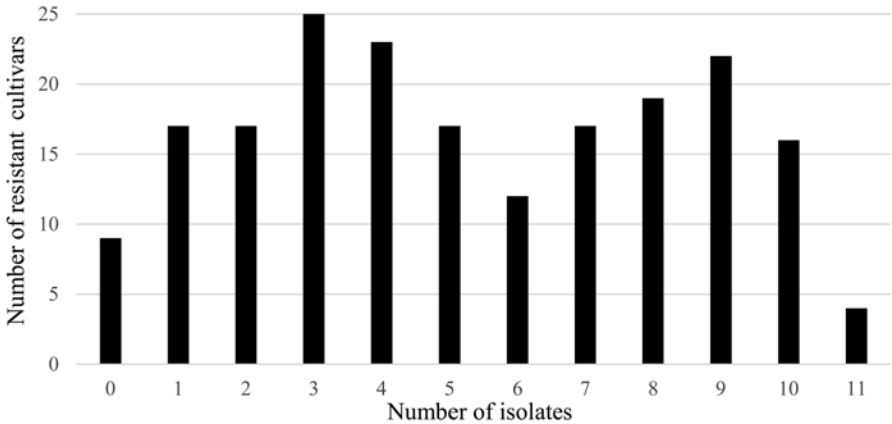

Fig. 2. Distribution of the number of rice lines that were resistant to 0 isolates, 1 isolate, 2 isolates, etc. For example, 9 rice lines were not resistant to any isolates and 4 lines were resistant to all 11 reference isolates.

Diamond, a High Yielding, Very Short Season, Long-Grain Rice Variety

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ABSTRACT

Diamond, a new short season, very high yielding, long-grain rice cultivar, was derived from the cross Francis/Roy J. Diamond has been approved for release to qualified seed growers for the summer of 2016. The major advantages of Diamond are its high yield potential, long kernel length, low chalk and its early maturity. Diamond is a non-semidwarf standard long-grain rice cultivar with lodging resistance approaching that of Roy J. Diamond is very susceptible to false smut, susceptible to rice blast, sheath blight, and kernel smut, and moderately susceptible to bacterial panicle blight.

INTRODUCTION

Diamond was developed in the rice improvement program at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC), Stuttgart, Ark., and has been released to qualified seed growers for the 2016 growing season. Diamond has very high rough rice grain yield, good milling yield, and earliness compared to Roy J. It is approximately 1 to 2 days later in maturity than LaKast and 4 to 5 days earlier than Roy J. It is similar in height to Roy J and LaKast, and has straw strength approaching that of Roy J. Diamond was developed with the use of rice grower check-off funds distributed by the Arkansas Rice Research and Promotion Board.

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PROCEDURES

Diamond rice (*Oryza sativa* L.), is a very high yielding, short season, long-grain rice cultivar developed by the Arkansas Agricultural Experiment Station. Diamond originated from the cross Francis/Roy J (cross no. 20082221), made at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center, (RREC), Stuttgart, Ark., in 2008. Diamond is named for the diamond state of Arkansas and because it is a diamond of a variety. Francis is a high yielding long-grain rice described by Moldenhauer et al. (2007). Roy J (Moldenhauer et al., 2010) is a long-grain lodging resistant high yielding rice. The experimental designation for early evaluation of Diamond was STG10L-08-129, starting with a bulk of F_5 seed from the 2010 panicle row P-08-129. Diamond was tested in the Arkansas Rice Performance Trials (ARPT) and the Cooperative Uniform Regional Rice Nursery (URRN) during 2013 to 2015 as entry RU1301084 (RU number indicated Cooperative Uniform Regional Rice Nursery; 13 indicates year entered was 2013; 01 indicates Stuttgart, Ark.; and 084 its entry number).

In 2013, the ARPT was conducted at five locations in Arkansas: RREC; Northeast Research Extension Center, (NEREC), Keiser Ark.; Pine Tree Research Station, (PTRS), near Colt, Ark.; a Clay County producer field (CCPF) near Corning Ark.; and a Desha County producer field (DCPF) near Dumas, Ark. In 2014 the tests were conducted at the RREC, PTRS, CCPF, and DCPF; in 2015 the trials were grown at RREC, NEREC, PTRS, CCPF, and DCPF. The tests had four replications per location to reduce soil heterogeneity effects and to decrease the amount of experimental error. Diamond was also grown in the URRN at the RREC; Crowley, Louisiana; Stoneville, Mississippi; Beaumont, Texas, and at Malden, Missouri during 2013 to 2015. This test has three replications per location. Data collected from these tests included plant height, maturity, lodging, percent head rice, percent total rice, 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, 2013). Agronomic and milling data are presented in Tables 1 and 2. Disease ratings, which are indications of potential damage under conditions favorable for development of specific diseases, have been reported on a scale from 0 = least susceptible to 9 = most susceptible, or as very susceptible (VS), susceptible (S), moderately susceptible (MS), moderately resistant (MR), and resistant (R). Straw strength is a relative estimate based on observations of lodging in field tests using the scale from 0 = very strong straw to 9 = very weak straw, totally lodged.

RESULTS AND DISCUSSION

Rough rice grain yields of Diamond have consistently ranked as one of the highest in the ARPT. In 14 ARPT tests (2013-2015), Diamond, LaKast, Roy J, Taggart, Wells, Mermentau, and RiceTec XL753 averaged yields of 210, 189, 195, 191, 183, 177, and 239 bu/acre, respectively (Table 1). Data from the URRN conducted at Arkansas during 2013-2015, showed that Diamond had an average grain yield of 246 bu/acre which com-

pared favorably with those of LaKast, Roy J, Taggart, Francis, Wells, and Mermentau, at 244, 214, 221, 228, 222, and 219 bu/acre, respectively (Table 2). Milling yields (mg g^{-1} whole kernel:mg g^{-1} total milled rice) at 120 mg/g moisture from the ARPT, 2013-2015, averaged 610:690, 600:700, 620:700, 580:700, 590:700, 650:700, and 570:700, for Diamond, LaKast, Roy J, Taggart, Wells, Mermentau, and RT XL753, respectively. Milling yields for the URRN in Arkansas during the same period of time, 2013-2015, averaged 650:710, 650:730, 630:710, 630:720, 660:720, 660:720, and 680:720, for Diamond, LaKast, Roy J, Taggart, Francis, Wells, and Mermentau, respectively.

Diamond is a short to very short season variety close to the maturity of LaKast and about 4 to 5 days earlier than Roy J. 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) Diamond, LaKast Francis, Wells, LaGrue, Cocodrie, and Roy J rated 2, 4, 4, 3, 5, 2, and 1, respectively. Diamond is 40 inches in plant height which is similar to Roy J and Wells.

Diamond, like Francis, and LaKast, is susceptible to common rice blast [*Pyricularia grisea* (Cooke) Sacc.] races IB-1, IB-33, IB-49, IC-17, IE-1, and IE-1K with summary ratings in greenhouse tests of 6, 6, 6, 6, 5, and 7, respectively, using the standard disease scale of 0 = immune, 9 = maximum disease susceptibility. Diamond is rated S to sheath blight (*Rhizoctonia solani* Kühn) which compares with Francis (MS), Wells (S), Roy J (MS), and LaKast (S), using the standard disease ratings of R = resistant, MR = moderately resistant, MS = moderately susceptible, S = susceptible, and VS = very susceptible to disease. Diamond is rated S for kernel smut [*Tilletia barclayana* (Bref.) Sacc. & Syd. in Sacc.], which compares to Francis (VS), Roy J (VS), Wells (S), Mermentau (S), and Taggart(S). Diamond is rated MS to bacterial panicle blight caused by *Burkholderia* species compared to Francis (VS) and Roy J (S) and VS to false smut [*Ustilaginoidea virens* (Cooke) Takah].

Plants of Diamond have erect culms, green erect leaves, and glabrous lemma, palea, and leaf blades. The lemma and palea are straw colored with purple apiculi, many of which fade to straw at maturity. Milled kernels of Diamond are long at 7.15 mm compared to LaKast, Roy J, Wells, Taggart, and Mermentau at 7.47, 7.24, 7.16, 7.40, and 7.06 mm, respectively. Individual milled kernel weights of Diamond, LaKast, Roy J, Taggart, Wells, and Mermentau averaged 21.6, 21.8, 21.2, 22.7, 21.7, and 19.8 mg/kernel, respectively, in the ARPT 2013-2014, data from the Riceland Quality Laboratory.

The endosperm of Diamond is nonglutinous, nonaromatic, and covered by a light brown pericarp. Rice quality parameters indicate that Diamond has typical southern U.S. long-grain rice cooking quality characteristics as described by Webb et al. (1985). Diamond has an average apparent starch amylose content of 22.8 g kg^{-1} and an intermediate gelatinization temperature (70 to 75 °C), as indicated by an average alkali (17 g kg^{-1} KOH) spreading reaction of 3 to 5.

SIGNIFICANCE OF FINDINGS

The release of Diamond provides producers with a very-high yielding, short season, long-grain rice replacement for Wells or Francis. It has the added benefit of

yield stability over time, yielding an average of 10 to 15 bushels better than any other pure-line variety for the past three years.

ACKNOWLEDGMENTS

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Table 1. Three-year average for yield and three-year average for the agronomic data from the 2013 to 2015 Arkansas Rice Performance Trials for Diamond and other cultivars.

Cultivar Cultivar	Grain type[a]	Yield[b] 2013	2014	2015	Mean	Height[c]	50% heading[d]	Chalky kernels[e]	Milling[f]
		----------(bu/acre)----------				(in.)	(days)		(HR:TOT)
Diamond	L	226	218	186	210	40	81	1.40	61:69
LaKast	L	203	202	162	189	41	80	1.04	60:70
Roy J	L	210	207	169	195	41	85	1.13	62:70
Taggart	L	205	200	167	191	43	84	1.02	60:70
Wells	L	196	192	161	183	40	82	1.37	59:70
Mermentau	L	190	181	161	177	37	80	1.88	65:70
RT XL753	L	245	259	212	239	44	78	2.13	57:70

[a] Grain type L = long-grain.
[b] Yield trials in 2013 consisted of five locations, Rice Research and Extension Center, (RREC), Stuttgart Ark.; Pine Tree Research Station, (PTRS), near Colt, Ark.; Northeast Research and Extension Center, (NEREC), Keiser, Ark.; Clay County Farmer Field, (CCPF), Corning, Ark.; and Desha County Producer Field (DCPF), in 2014 the successful trials were grown at RREC, PTRS, CCPF, and DCPF; in 2015 the trials were at RREC, PTRS, NEREC, CCPF, and DCPF.
[c] Height data is from 2013-2015.
[d] Heading information from 2013-2015.
[e] Data for chalk is from 2013-2014 Riceland Grain Quality Laboratory data.
[f] Milling figures are head rice : total milled rice 2013-2015.

Table 2. Data from the 2013 to 2015 Uniform Regional Rice Nursery for Diamond and other check cultivars.

	Yield[a]				Arkansas yield						
Cultivar	2013	2014	2015	Mean	2013	2014	2015	Mean	Height[b]	50% heading[c]	Milling[d]
	(bu/acre)								(in.)	(days)	(HR:TOT)
Diamond	219	235	209	221	244	261	234	246	43	88	65:71
LaKast	218	243	202	221	241	258	232	244	44	86	65:72
Wells	199	213	183	198	227	251	189	222	44	90	66:72
Francis	195	229	186	203	217	259	208	228	43	89	66:72
Taggart	211	222	211	217	231	235	197	221	48	93	63:72
Roy J	215	229	184	209	240	221	180	214	45	95	63:71
Mermentau	201	208	194	201	235	221	202	219	40	89	68:72

[a] Arkansas = Rice Research and Extension Center, Stuttgart, Ark.
[b] Height data from Arkansas 2013-2015 only.
[c] Heading data from Arkansas 2013-2015 only.
[d] Milling figures are %Head Rice : %Total Milled Rice.

Genetic Basis of Altered Grain Quality in Different Rice Cultivars Under High Nighttime Temperature

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ABSTRACT

This study was focused on understanding the genetic basis of grain quality, and testing the chalkiness of diverse rice cultivars treated with high nighttime temperature (HNT). Our results confirmed previous field and controlled-climate experiments on the effect of HNT on the chalkiness of Bengal, M204, Cypress, LaGrue, and Wells, with Bengal and Cypress being least affected. In addition, in our study the higher yield rice (HYR)-Nipponbare transgenic line, Roy J, and Cheniere had low chalk, whereas Nipponbare and CL151 had higher chalk. Gene expression and genetic variation analysis provided valuable information on the potential role of several starch biosynthetic pathway genes and the functional polymorphisms in regulating grain quality in the cultivars studied.

INTRODUCTION

High nighttime temperature (HNT) during grain filling is one of the major causes of rice chalkiness in both field and controlled climate experiments (Cooper et al., 2006; Counce et al., 2005; Lanning et al., 2011; Peng et al., 2004). Chalkiness is a critical attribute of rice quality and chalk percentage is related to reduced head rice yield. Especially in premium rice markets, chalk incidence reduces buyer acceptance, appearance, and overall evaluations of rice quality. It has been suggested that the opaque appearance of chalky grain is due to loosely packed amyloplasts and starch granules (Singh et al., 2003). Existence of greater genetic variation for grain quality under HNT has been observed in rice cultivars (Cooper et al., 2008). Cooper et al. (2008) reported that rice cultivars subjected to HNT during grain filling under a controlled-environment showed different degrees of chalkiness. Gene expression analysis of the developing caryopses treated to high day/night temperatures revealed a decrease in transcript levels of sucrose and starch synthesis genes and an increase in transcript levels of starch

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degradation genes (Yamakawa and Hakata, 2010). However, the genetic basis of altered grain quality under HNT has not been explored so far. Therefore, this study was focused on understanding the genetic control of altered grain quality in selected U.S. rice cultivars. Here we describe the screening of an extended panel of rice cultivars for altered grain quality parameters under HNT, using controlled growth chamber conditions, and identify functional gene markers for rice grain quality by gene expression and genetic variation analysis.

PROCEDURES

Plant Growth Conditions and Temperature Treatment

For grain quality measurements, plants at the R2 stage were treated to HNT of 28 °C while controls were maintained at 22 °C with constant day temperature of 30 °C. At physiological maturity, seeds were harvested and air dried. For gene expression studies, beginning at the R5 stage, rice plants were subjected to HNT; and the caryopses at R6 stage (soft to hard dough stage) were harvested as soon as the lights came on in the morning and frozen in liquid nitrogen. Grains were collected at grain maturity for chalk measurements.

Chalk Measurement

Rough rice was de-hulled using a manually operated de-huller (Rice Husker TR120, Kett Electric Laboratory, Tokyo, Japan). Chalkiness was measured using an image analysis system WinSeedle™ Pro 2005a (Regent Instruments, Quebec, Canada) and expressed as percent of grain projected area. Data are the means of two biological replicates with each replicate measured twice using 100 grain. A significant difference between treatments within the cultivar was determined by pairwise comparisons of means using Student's *t*-test.

Transcriptome Analysis

The total caryopsis RNA was isolated using TRIZol reagent at the milky dough stage. Sequencing of RNA was carried out using Illumina High-Seq 2000 (Illumina, San Diego, Calif.) platform using two biological replicates per sample (Michigan State University Genomics core facility). Differentially expressed genes were identified as described in Trapnell et al. (2010). For genome sequencing, genomic DNA was isolated from Bengal, M204, Cypress, and LaGrue using the DNeasy Plant Mini Kit (Qiagen, Inc, Valencia, Calif.). The genome sequencing was carried out using Illumina High-Seq 2000 platform and single nucleotide polymorphisms (SNPs) were predicted as described in Srivastava et al. (2014).

RESULTS AND DISCUSSION

High nighttime temperature effect on the chalkiness of 11 cultivars/genotypes [Bengal, Cypress, LaGrue, M204, Nipponbare, HYR-Nipponbare a transgenic line

(Ambavaram et al., 2014), Cheniere, CL151, Roy J, Starbonnet, and Wells] was studied. High nighttime temperatures increased chalkiness, and reduced grain width and length compared to the control in all the cultivars (Fig. 1). The chalkiness of short- and medium-grain cultivars Nipponbare and M204 were higher than in the HYR-Nipponbare line and Bengal, respectively. Overall, Bengal, Cypress, Roy J, and Cheniere showed the lowest chalk; whereas LaGrue showed the highest chalk among the cultivars studied. These results corroborate previous findings that Bengal and Cypress showed least chalkiness under HNT among the medium- and large-grain cultivars, respectively, when tested under controlled environmental conditions as well as under field conditions (Cooper et al., 2008; Ambardekar et al., 2011). In addition to chalkiness, HNT also reduced the grain length of Bengal, M204, and Wells, and grain width of HYR-Nipponbare, Nipponbare, Bengal, M204, Cypress, Roy J, and CL151 (Fig. 1B and C). Decrease in grain width of Bengal, M204, and Cypress was also observed in previous studies, both under controlled environment and field conditions (Counce et al., 2005; Cooper et al., 2008).

Gene expression analysis by RNA sequencing in the R6 stage caryopses of all cultivars subjected to HNT showed differential expression of several starch biosynthetic pathway genes among the low and higher chalk cultivars. For example, the expression of GBSSI gene, the primary determinant of amylose content, in good quality cultivars such as HYR-Nipponbare, Bengal, Cypress, and Roy J was higher compared to the cultivars Nipponbare, M204, and LaGrue (Fig. 2). Similarly, AGPL2, another key gene in starch biosynthesis also showed higher expression in Bengal and Cypress compared to M204 and LaGrue (Fig. 2). These results suggest that the differential expression of starch biosynthetic pathway genes under HNT determine grain quality. Cultivars having better expression of one or more of these genes may have improved quality over those with lower gene expression.

Further, genome sequence analysis of the four cultivars (Bengal, M204, Cypress, and LaGrue) was analyzed for SNPs in starch biosynthetic pathway genes including their promoters. The analysis identified several SNPs which are present in low chalk cultivars but absent in cultivars with higher chalk (Table 1). For example, SSIIIa and BEI genes from Bengal have multiple SNPs which are also present in Cypress but absent in M204 and LaGrue. Similarly, BEIIb genes from Bengal and Cypress have many SNPs, which are absent in M204 and LaGrue. Interestingly, several functional nonsynonymous SNPs, potentially changing the protein, were found in genes of the low chalk cultivars which were absent in genes of cultivars with high levels of chalk (Table 1). These variations in SNPs might be contributing to the differential expression of starch genes and their activity, resulting in altered amylose content and amylopectin structure under HNT.

SIGNIFICANCE OF FINDINGS

Our results comparing 11 genotypes under similar controlled conditions confirmed the previous findings (Counce et al., 2005; Cooper et al., 2008) that under HNT, Bengal and Cypress showed reduced chalkiness compared to M204, LaGrue, and Wells.

In addition, Roy J and Cheniere had lower chalk than CL151. Our results suggest that controlled condition screens for HNT response are very valuable in identifying chalkiness parameters before testing the cultivars under field conditions which can be unpredictable. Gene expression and genetic variation analysis provided useful indicators of the genetic basis for differential grain chalk formation between the cultivars. However, the results do not sufficiently explain the varying chalky phenotypes observed among different cultivars under HNT. Therefore, further confirmation of functional isoforms of the genes and validation of the SNPs can identify the real cause of differential chalkiness in the tested cultivars that can be used in the breeding program.

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Table 1. Single nucleotide polymorphisms (SNPs) in starch biosynthesis genes of diverse rice cultivars differing in grain quality.

Gene name	Bengal	M204	Cypress	LaGrue
OsAGPL1	0	0	0	0
OsAGPL2	2	0	2	0
OsAGPS1	0	0	0	0
OsAGPS2	2	0	27	4
OsGBSSI	0	0	2 (1 non-syn)	0
OsSSI	0	0	0	0
OsSSIIa	0	0	1 (non-syn)	0
OsSSIIIa	3	2	38 (7 non-syn)	8 (1 non-syn)
OsBEI	7	0	14 (1 non-syn)	1
OsBEIIb	25 (2 non-syn)	1	35 (2 non-syn)	5
OsISA1	0	0	0	0

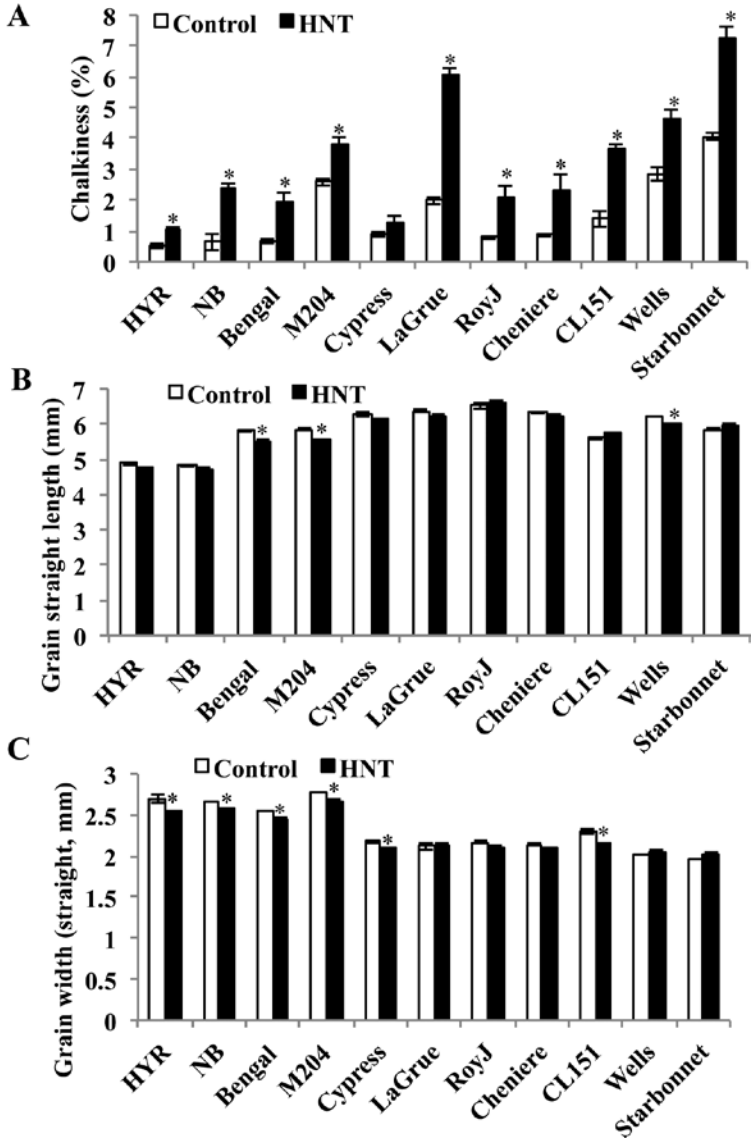

Fig. 1. Effect of high nighttime temperatures (HNT) on chalkiness, length, and width of brown grain of diverse rice cultivars. Plants at R2 stage were treated to HNT of 28 °C until maturity with controls maintained at 22 °C. The daytime temperature was kept constant at 30 °C. At physiological maturity, seeds were harvested, air dried, and de-hulled using a manually operated de-huller (Rice Husker TR120). (A) Chalkiness, (B) grain length and (C) grain width was measured using an image analysis system (WinSeedle™ Pro 2005a) and expressed as percent of grain projected area. Data are the means of two biological replicates with each replicate measured twice using 100 grain. An * indicates significant difference at *P* < 0.05, Student's *t*-test.

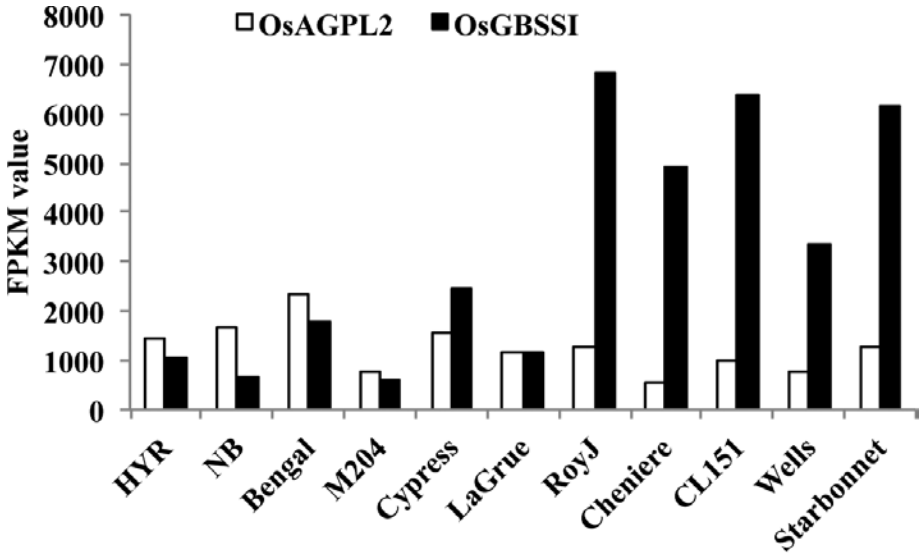

Fig. 2. Expression of starch biosynthetic pathway genes in different rice cultivars treated to high nighttime temperatures (HNT). Caryopses at R6 stage treated to HNT were used to isolate total RNA and mRNA was sequenced using Illumina High-Seq 2000 platform (Michigan State University Genomics core facility). The reads were mapped to the rice reference genome sequence (MSU 7.0) with Tophat 1.3.1 and mapped reads were assembled into transcripts by Cufflinks. The differentially expressed genes were identified by using Cuffdiff. The expression values of GBSSI and AGPL2 under HNT in rice cultivars is given.

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

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ABSTRACT

To reflect the recent changes of the state rice industry and streamline the delivery of new and improved rice varieties to the Arkansas rice growers, the new medium-grain rice breeding project will expand its research areas and breeding populations to include both conventional and Clearfield medium-grain and semi-dwarf long-grain rice, as well as hybrid rice. Newest elite breeding lines/varieties from collaborating programs, as well as lines with diverse genetic origins will be actively collected, evaluated, and incorporated into the current crossing blocks for the programmed hybridization. To improve the efficiency and effectiveness, maximum mechanized-operation, multiple generations of winter nursery, and new technologies such as molecular marker-assisted selection (MAS) will also be rigorously pursued.

INTRODUCTION

Medium-grain rice is the important component of Arkansas rice. Arkansas ranks second in medium-grain rice production in the United States only behind California. During 2005-2014, an average of 0.15 million acres of medium-grain rice was grown annually, which makes up about 10% of total state rice acreage (USDA-ERS, 2015). Planted acres of medium-grain rice in Arkansas in the last decade have varied from a high of 243,000 acres in 2011 (21% of total rice planted in Ark.) to a low of 99,000 acres in 2008 (7% of total rice planted in Ark.).

A significant portion of Arkansas rice area was planted to semi-dwarf long-grain varieties, such as CL111, CL151, and Mermentau. However, locally developed semi-dwarf varieties offer advantages including better stress tolerance and more stable yields. Improved semi-dwarf long-grain lines also can be directly adopted by the newly

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established hybrid breeding program. Since genetic potential still exists for further improvement of current varieties, rice breeding efforts should and must continue.

The inter-subspecies hybrids between *indica* male sterile lines and tropical *japonica* restorer/pollinator lines that were first commercialized in the United States in 1999 by RiceTec have a great yield advantage over conventional pure-line varieties (Walton, 2003). However the 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 to overcome 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 will be carried out on backcross or topcross progenies on 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), Stuttgart, Ark., and the winter nursery in Lajas, Puerto Rico. Pedigree and modified single seed descent will be the primary selection technology 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 having a good combination of these characteristics will be further screened in the laboratory for traits such as kernel size and shape, grain chalkiness, and grain uniformity. Milling small samples, as well as the physicochemical analysis at the USDA Rice Quality Laboratory at the Dale Bumpers National Rice Research Center near Stuttgart, Ark., and at Riceland Foods, Inc. Research and Technology Center, Stuttgart, Ark., will be conducted to eliminate lines with evident quality problems and/or maintain standard U.S. rice quality of different grain types. Yield evaluations include the Stuttgart Initial Yield Trial (SIT) and Clearfield SIT (CSIT) at the RREC; the Advanced Yield Trial (AYT) at the RREC, the Pine Tree Research Station (PTRS), near Colt, Ark. and the Northeast Research and Extension Center (NEREC), Keiser, Ark.; the Arkansas Rice Performance Trials (ARPT) conducted by Jarrod Hardke, the rice extension 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 will be provided to cooperating projects for the further evaluation of resistance to sheath blight, blast, and panicle blight, grain and cooking/processing quality, and nitrogen fertilizer requirements. All lines entered in the SIT or CSIT and beyond will be planted as headrows 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 2015 included 427 transplanted F_1 populations, 625 space-planted F_2 populations, and 53,450 panicle rows ranging from F_3 to F_6. Visual selection on approximately 625,000 individual space-planted F_2 plants resulted in a total of 31,000 panicles, which will be grown as F_3 panicle rows in 2016. From 53,450 panicle rows, 3981 were selected for advancement to the next generation, while 1753 rows which appeared to be uniform and superior were bulk-harvested as candidates for the 2016 SIT or CSIT trials. In the 2015 Clearfield (CL) preliminary yield trial (CSIT), we evaluated 557 new breeding lines which included 462 semidwarf CL long-grain and 95 CL medium-grain lines. In the SIT trial, 307 new semidwarf breeding lines were tested, which consist of 171 long-grain and 136 medium-grain lines. A new 60-entry Advanced Yield Trial (AYT) was initiated and conducted at PTRS and NEREC in addition to RREC. A number of breeding lines showed yield potential similar to or better than the check varieties (Tables 1-4). Twenty six advanced breeding lines were evaluated in the ARPT and/or multi-state URRN trials. Results of those entries and selected check varieties were listed in Table 5. Three Puerto Rico winter nurseries of 10,500 rows were planted, selected, harvested, and/or advanced throughout 2015. A total of 592 new crosses were made to incorporate desirable traits from multiple sources into adapted Arkansas rice genotypes, which included 211 CL long-grain, 59 CL medium-grain, 101 semidwarf conventional long-grain, 81 conventional medium-grain, and 16 hybrid line crosses, as well as 96 hybrid test crosses and 28 hybrid backcrosses.

The conventional medium-grain line RU1301021 continued showing excellent yield potential, good milling, and superior grain quality in trials across Arkansas and the mid-South in 2015. It was approved for the formal release as Titan by the University of Arkansas System Division of Agriculture in February 2016. Foundation seed was produced, and is available to seed rice growers for the 2016 growing season. The semi-dwarf CL long-grain line 15AR1024 (RU1501024) and CL medium-grain line 15AR1111 (RU1501111) were selected for purification and increase in Lajas Puerto Rico in winter 2015 for their superior yielding potential and excellent milling and grain quality. One hundred seventy-five breeding lines that outperformed commercial check varieties in AYT, CSIT, and SIT trials were selected and were further evaluated in the laboratory before entering 2016 ARPT and/or URRN trials.

SIGNIFICANCE OF FINDINGS

Successful development of medium-grain variety Titan offers producers options in their choice of variety and management systems for Arkansas rice production. Continued utilization of new germplasm through exchange and introduction remains important for Arkansas rice improvement.

ACKNOWLEDGMENTS

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Table 1. Performance of selected Clearfield long-grain experimental lines and check varieties in the Clearfield Stuttgart Initial Trial (CSIT) at the Rice Research and Extension Center near Stuttgart, Ark., 2015.

Variety/Line	Pedigree	Seedling vigor[a]	Days to 50% heading	Plant height	Yield	Milling yields	
						Head rice	Total rice
			(days)	(cm)	(bu/acre)	---------- (%)	----------
15CSIT409[b]	RU1102192/4/WLLS/CFX-18/3/CFX-18//CCDR/…	3.0	78	116	234	68.8	70.9
15CSIT324[b]	RU1102034/4/CCDR/JEFF/3/CFX-18//CCDR/…	5.0	78	118	222	69.2	71.7
15CSIT397[b]	CL172/RU1102192	4.5	77	106	220	68.6	71.1
15CSIT343[b]	RU1102034/RU1202082	5.5	81	119	220	64.7	70.5
15CSIT568[c]	RU0902125/CL151	4.0	78	113	228	61.2	68.2
15CSIT532[c]	CCDR//CCDR/JEFF/3/CL131/4/RU1302045	4.5	79	120	228	68.0	71.2
15CSIT550[c]	STG10IMI-05-034//RU0902155/RU0902131	4.5	79	105	223	68.8	72.8
15CSIT515[c]	RU1102034/RU1302045	4.0	79	113	222	69.2	71.6
15CSIT754[d]	RU1302048/RU1302045	4.5	67	113	224	67.9	70.8
15CSIT708[d]	RU1102028/CL111	3.0	67	111	222	68.2	71.1
15CSIT742[d]	RU1302045/MRMT	4.0	69	114	222	67.4	69.6
CL151[b]	CL151	3.5	78	106	185	66.1	70.9
CL151[c]	CL151	4.0	78	113	212	66.8	70.2
CL151[d]	CL151	3.0	68	106	197	69.8	72.5
CL172[c]	CL172	5.5	80	105	213	66.3	70.0

[a] A subjective 1 to 7 rating taken at emergence, 1 = perfect stand and 7 = no stand.
[b] Planted on 22 April.
[c] Planted on 9 May.
[d] Planted on 23 May.

Table 2. Performance of selected Clearfield medium-grain experimental lines and check varieties in the Clearfield Stuttgart Initial Trial (CSIT) at the Rice Research and Extension Center near Stuttgart, Ark., 2015.

Variety/Line	Pedigree	Seedling vigor[a]	Days to 50% heading	Plant height	Yield	Milling yields	
						Head rice	Total rice
			(days)	(cm)	(bu/acre)	---------- (%)	----------
15CSIT465[b]	RU1202065/JPTR	4.5	77	105	232	66.6	68.6
15CSIT475[b]	RU1202168/JPTR	4.0	78	101	220	62.0	68.6
15CSIT429[b]	RU1202168//9865216DH2/EARL	4.0	80	99	205	59.4	67.1
15CSIT463[b]	JPTR/RU1202068	5.0	81	113	203	67.3	69.0
15CSIT472[b]	RU1202168//RU0602162/RU0502031	4.0	82	106	202	69.1	71.1
15CSIT479[b]	STG09PR-82-037/RU1202068	3.5	78	95	199	60.2	68.0
15CSIT757[c]	RU1301124/CL261	5.5	68	117	222	64.3	67.7
15CSIT782[c]	BNGL/CL161/4/9502065/3/MERC//MERC/…	5.0	72	113	220	64.5	67.0
15CSIT779[c]	STG10PR-05-022/RU1201087//STG10PR-08-077/ M207	3.5	63	106	204	62.5	66.7
15CSIT765[c]	RU1202068/RU1301021	4.0	68	122	202	65.4	66.9
15CSIT758[c]	RU1301021/RU1202168	5.0	73	115	200	63.4	67.4
CL172[b]	CL172	4.0	79	102	187	66.3	70.0
CL271[b]	CL271	4.0	79	97	179	64.8	67.1
CL151[b]	CL151	3.0	68	106	197	67.6	70.9
CL271[c]	CL271	3.0	79	101	183	63.4	71.2

[a] A subjective 1-7 rating taken at emergence, 1 = perfect stand and 7 = no stand.
[b] Planted on 22 April.
[c] Planted on 23 May.

Table 3. Performance of selected conventional medium-grain experimental lines and check varieties in the Stuttgart Initial Trial (SIT) at the Rice Research and Extension Center near Stuttgart, Ark., 2015.

Variety/Line	Pedigree	Seedling vigor[a]	Days to 50% heading	Plant height	Yield	Milling yields	
						Head rice	Total rice
			(days)	(cm)	(bu/acre)	---------- (%)	----------
15SIT794[b]	JPTR/RU1001099	5.0	97	106	238	65.4	66.1
15SIT818[b]	RU1301121/JPTR	4.0	90	104	216	66.4	67.1
15SIT792[b]	JPTR/RU1001099	5.5	98	100	213	65.1	65.8
15SIT828[b]	BNGL/SRICO/4/9502065/3/BNGL//MERC/RICO	5.0	96	98	210	66.8	67.7
15SIT821[b]	RU1301133/JPTR	4.0	93	101	209	65.5	66.6
15SIT802[b]	EARL/4/ORIN//MERC/RICO/3/9602134	4.5	93	101	208	62.9	63.9
15SIT849[b]	9902028/3/BNGL//MERC/RICO/4/JPTR	6.0	95	95	208	66.9	68.0
15SIT786[b]	JPTR/J062	5.0	97	97	208	66.0	66.7
15SIT898[c]	EARL/9902028//JPTR	4.0	79	101	258	57.7	65.7
15SIT916[c]	JPTR/RU1301021	5.0	76	101	244	60.8	67.8
15SIT886[c]	EARL/9902028//RICO/BNGL	5.0	78	102	239	65.5	67.4
15SIT899[c]	EARL/9902028//JPTR	4.5	78	95	232	61.0	66.1
15SIT917[c]	JPTR/RU1301021	5.0	76	96	230	63.6	68.0
Jupiter[c]	Jupiter	4.0	80	106	232	65.8	67.1
Titan[b]	Titan	4.5	90	101	216	62.5	67.2

[a] A subjective 1 to 7 rating taken at emergence, 1 = perfect stand and 7 = no stand.
[b] Planted on 8 April.
[c] Planted on 9 May.

Table 4. Performance of selected conventional long-grain experimental lines and check varieties in the Stuttgart Initial Trial (SIT) at the Rice Research and Extension Center near Stuttgart, Ark., 2015.

Variety/Line	Pedigree	Seedling vigor[a]	Days to 50% heading	Plant height	Yield	Milling yields	
						Head rice	Total rice
			(days)	(cm)	(bu/acre)	---------- (%)	----------
15SIT710[b]	MRMT/RU0502068	4.5	99	104	246	68.3	70.1
15SIT666[b]	CTHL/RU1002192	5.0	98	105	235	69.4	71.6
15SIT758[b]	RU1102034/RU1002128	5.0	98	112	233	70.2	72.1
15SIT636[b]	CCDR/CPRS	4.5	99	107	232	65.7	67.9
15SIT726[b]	CHNR/CTHL	5.5	99	109	228	68.1	70.4
15SIT757[b]	RU1102034/RU1002128	4.0	99	111	228	68.5	70.6
15SIT703[b]	CCDR/CHNR	5.0	97	114	225	68.0	70.3
15SIT633[b]	RU0502068/RU1002128	5.0	101	110	224	68.3	69.9
15SIT683[b]	RU0802134/RU0902125	6.0	99	111	223	68.7	70.7
15SIT669[b]	RU0902034/RU0502068	5.5	100	105	220	68.0	70.4
15SIT883[c]	RU1102192/RU1102034	4.0	79	108	225	60.5	68.8
CL151[b]	CL151	5.0	95	109	205	67.6	70.9
LaKast[b]	LaKast	5.0	95	117	245	63.1	69.0
Mermentau[b]	Mermentau	5.0	99	104	201	64.0	68.3
Roy J[b]	Roy J	5.0	102	111	189	61.6	69.3

[a] A subjective 1 to 7 rating taken at emergence, 1 = perfect stand and 7 = no stand.
[b] Planted on 8 April.
[c] Planted on 9 May.

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, 2015.

Variety/Line	Pedigree	Grain type[a]	Days to 50% heading	Plant height	Yield	Milling yields	
						Head rice	Total rice
			(days)	(cm)	(bu/acre)	---------- (%)	----------
RU1501024	CL111/3/CCDR//9502008/LGRU	CL	88	99	186	63.7	71.6
RU1501027	NPTN//BNGL/CL161	CM	89	100	200	65.4	69.8
RU1501030	CPRS/KBNT//9502008-A	L	86	100	186	63.7	71.7
RU1501061	CL111//CCDR/0502085	CL	86	97	181	62.1	70.3
RU1501111	BNGL/CL161/4/9502065/3/MERC//MERC/…	CM	87	101	192	62.4	71.2
RU1501121	CL111/CCDR	CL	85	102	185	62.9	70.2
RU1501124	KATY/CPRS//JKSN/3/AR1188/CCDR/4/CFX-29/ CCDR	CL	85	106	200	64.4	71.3
RU1501127	CCDR/RU0801167	L	88	104	187	65.8	71.7
RU1501130	CPRS/KBNT//CFX29/CCDR/3/06CFP952	CL	88	103	187	64.5	70.5
Jupiter	Jupiter	M	89	93	214	65.9	69.5
Titan	Titan	M	84	98	204	62.5	69.4
CL151	CL151	CL	86	96	209	63.0	71.2
CL172	CL172	CL	89	95	176	64.4	71.2
CL271	CL271	CM	90	98	188	63.9	70.4
LaKast	LaKast	L	86	106	202	57.2	71.2
Mermentau	Mermentau	L	86	95	194	64.5	71.3

[a] CL = Clearfield long-grain, CM = Clearfield medium-grain, L = long-grain, and M = medium-grain.

Development of Male Sterile Line for Hybrid Rice Production

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ABSTRACT

Production of hybrid rice in Arkansas has been growing rapidly in the last decade due to its net revenue advantage over inbred lines (Lyman and Nalley, 2013). Currently, over 40% of Arkansas' rice fields consist of hybrid rice production (Berger et al., 2014). Since 2010, the University of Arkansas, as one of the major crop variety developers in the state, has aimed to release hybrid rice cultivars with high yield and acceptable seed quality. Despite high yield, poor eating quality has been one of the main issues in hybrid rice production (Khush et al.,1988). One solution to address this issue is to develop male sterile lines with desirable phenotypic characteristics and eating quality. Therefore, in summer 2015, 9 BC_2F_2 populations resulting from 2 crosses between 236s, a male sterile line developed at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC) near Stuttgart, Ark., and 2 elite rice cultivars, Francis and Cocodrie were grown in field conditions. After extensive phenotypic and genotypic evaluations, 59 BC_2F_2 single plants possessing desirable genes associated with eating quality were selected. In the next phase, the selected 59 BC_2F_3 lines will be planted in summer 2016 and the best lines will be selected as new male sterile lines.

INTRODUCTION

Hybrid rice is defined as the first generation (F_1) seeds produced by a cross between two different types of rice: one is a male sterile line used as a female parent and an elite cultivar as a male parent. Due to a phenomenon known as heterosis, hybrid rice varieties outperform their parents; hybrid rice cultivars can often produce 15% to 20% seed yield more than rice inbred cultivars. Moreover, hybrid rice shows better resistance to unfavorable environmental conditions such as salinity and drought. To reach maximum seed production and yield, F_1 seed needs to be produced every planting season (Virmani et al., 1997, 2003). In 2010, the University of Arkansas System Division of Agriculture established the rice hybrid program to address the needs of very high yield with good

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seed quality of hybrid rice cultivars in the mid-southern United States. Since then, several male sterile lines have been developed (Yan et al., 2012). However, the significant issue in hybrid rice production is low eating quality characteristics such as: milling quality, chalkiness, high or low amylose content, and low gelatinization temperature. A major goal in 2015 was to develop new male sterile lines containing desirable agronomic traits which can be used in hybrid rice production.

PROCEDURES

In 2014, two BC_2F_1 populations resulting from crosses between 236s, an Arkansas male sterile line, and Cocodrie and Francis, two *Japonica* cultivars developed from Louisiana and Arkansas respectively, were tested via molecular markers to evaluate some agronomic and eating quality traits including plant height, grain type, aroma, amylose content, gelatinization temperature (GT hereafter) as well as blast resistance. Rice grain types are classified as long, medium, and short; long-grain rice is the favorable trait in hybrid rice. Amylose content is associated with texture of cooked rice. There are three classes of amylose content: low, medium, and high (Khush et al., 1988). The market demands a hybrid rice with the medium amylose content. Gelatinization temperature is related to the time required to cook rice. There are 3 classes of GT: high, intermediate, and low (Khush et al., 1988); intermediate temperature is the desirable one for long-grain rice, both pure-line and hybrid rice. Several blast disease resistance genes have been reported such as *Pi-ta*, *Pi-z*, and *Pi-ks*. Each gene confers resistance to some, but not all, blast isolates.

The results showed that the alleles attributed to these traits were in heterozygous condition that cause segregation in the next generation. Therefore, the foremost goal was to identify and select single plants containing desirable agronomic traits in homozygous condition. In 2015, nine BC_2F_2 lines including eight 236s × Cocodrie and one 236s × Francis were planted in field at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC), Stuttgart, Ark. All selected lines were semi-dwarf and non-aromatic rice. Each single plant from each line was tested via Simple Sequence Repeat (SSR) and Single Nucleotide Polymorphism (SNP) markers linked to the eating quality traits and blast resistance. In addition, four common rice cultivars including Bengal, Jupiter, Katy, Cypress, Pokhareli, Masino, and ZHE733 were used as checks.

RESULTS AND DISCUSSION

A total of 589 BC_2F_2 plants were tested via molecular study. The results revealed that 126 single plants (about 25% of whole population) were long-grain type with intermediate amylose content, 25% medium-grain with low amylose content, and 50% were segregating in grain size and amylose content. Only those 126 single plants exhibiting long-grain type with intermediate amylose content were selected for further evaluation. Molecular study on the GT trait showed that of 126 selected BC_2F_2 single plants, about 43% of single plants were medium-high, 11% low, and 46% were segregating.

The molecular study showed that these 126 plants possessed at least 1 gene conferring resistance to blast disease: all contain *Pi-ta* gene conferring resistance to blast disease, 8 plants contain *Pi-ks* gene at homozygous stage, but there was no single plant possessing *Pi-z* gene.

SIGNIFICANCE OF FINDING

After careful consideration, 59 BC_2F_2 single male sterile plants were selected, ratooned, and transferred from the farm to a greenhouse under controlled light and temperature conditions required for seed increase (Table 1). The amount of harvested seeds from each plant varied. These seeds will be planted as 59 plots in summer 2016 and will be evaluated for sterility and uniformity. The best plot will be selected as a new male sterile line developed by RREC. The selected line will be crossed with elite cultivars and the F_1 hybrid seeds will be tested for yield, in 2017 in a preliminary yield trial test.

Three BC_2F_1 populations resulted from cross between 811s, a male sterile line developed at the RREC; and three rice accessions Francis, RU0302143, and RU1201102 will be planted in fields and evaluated for agronomic and eating quality. Moreover, 811s and 236s will be planted in growth chamber to identify the genetic sources of sterility and determine the optimum day length and temperature threshold required by the plants to show sterility or fertility.

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Table1. Fifty-nine BC_2F_2 single plants possessing genes associated with eating quality.

Plant number	Progeny[a]	Grain type	Amylose	Gel temp	*Pi-k*	*Pi-ta*	*Pi-z*
P19-1-14	236s x CCDR	Long	Intermed-High	Med-High	S	R	S
P19-1-17	236s x CCDR	Long	Intermed-High	Med-High	S	R	S
P19-1-23	236s x CCDR	Long	Intermed-High	Med-High	S	R	S
P19-1-33	236s x CCDR	Long	Intermed-High	Med-High	S	[b]	S
P19-1-42	236s x CCDR	Long	Intermed-High	Med-High	S	R	S
P19-1-47	236s x CCDR	Long	Intermed-High	Med-High	S	R	S
P19-1-50	236s x CCDR	Long	Intermed-High	Med-High	S	R	S
P19-1-55	236s x CCDR	Long	Intermed-High	Med-High	S	R	S
P19-1-56	236s x CCDR	Long	Intermed-High	Med-High	S	R	S
P19-1-60	236s x CCDR	Long	Intermed-High	Med-High	S	R	S
P19-1-62	236s x CCDR	Long	Intermed-High	Med-High	S	R	S
P19-1-74	236s x CCDR	Long	Intermed-High	Med-High	S	R	S
P19-1-75	236s x CCDR	Long	Intermed-High	Med-High	S	R	S
P19-2-94	236s x CCDR	Long	Intermed-High	Med-High	Seg.		S
P19-2-98	236s x CCDR	Long	Intermed-High	Med-High	S	R	S
P19-2-110	236s x CCDR	Long	Intermed-High		S	R	S
P19-2-126	236s x CCDR	Long	Intermed-High	Med-High	Seg.	R	S
P19-2-134	236s x CCDR	Long	Intermed-High	Med-High	R	R	S
P19-2-135	236s x CCDR	Long	Intermed-High	Med-High	Seg.	R	S
P19-2-145	236s x CCDR		Intermed-High	Med-High	R	R	S
P19-2-148	236s x CCDR		Intermed-High	Med-High	Seg.	R	S
P19-2-159	236s x CCDR	Long	Intermed-High	Med-High	S	R	S
P19-2-169	236s x CCDR	Long	Intermed-High	Med-High	Seg.	R	S
P19-2-170	236s x CCDR	Long	Intermed-High	Med-High	R	R	S
P19-2-174	236s x CCDR	Long	Intermed-High	Med-High	Seg.	R	S
P19-2-187	236s x CCDR	Long	Intermed-High	Med-High	R	R	S
P19-2-203	236s x CCDR	Long	Intermed-High	Med-High	Seg.	R	S
P19-2-204	236s x CCDR	Long	Intermed-High	Med-High	S	R	S
P19-2-209	236s x CCDR	Long	Intermed-High	Med-High	S	R	S
P19-2-230	236s x CCDR	Long	Intermed-High	Med-High	Seg.	R	S
P19-2-238	236s x CCDR	Long	Intermed-High	Med-High	S	R	S
P19-2-244	236s x CCDR	Long	Intermed-High	Med-High	Seg.	R	S
P19-2-247	236s x CCDR	Long	Intermed-High	Med-High	Seg.	R	S
P19-2-249	236s x CCDR	Long	Intermed-High	Med-High	S	R	S
P19-3-262	236s x CCDR	Long	Intermed-High	Med-High	S	R	S
P19-3-265	236s x CCDR	Long	Intermed-High	Med-High	S		
P19-3-270	236s x CCDR	Long	Intermed-High	Med-High	S	R	S
P19-3-288	236s x CCDR	Long	Intermed-High	Med-High	S	R	S

continued

Table 1. Continued.

Plant number	Progeny[a]	Grain type	Amylose	Gel temp	*Pi-k*	*Pi-ta*	*Pi-z*
P19-3-307	236s x CCDR	Long	Intermed-High		S		S
P19-4-316	236s x FRNS	Long	Intermed-High	Med-High	S	R	S
P19-4-370	236s x FRNS	Long	Intermed-High	Med-High	S	R	S
P19-4-386	236s x CCDR	Long	Intermed-High	Med-High	S	R	S
P20-1-413	236s x CCDR	Long	Intermed-High	Med-High	S	R	S
P20-1-434	236s x CCDR	Long	Intermed-High	Med-High	S	R	S
P20-1-446	236s x CCDR	Long	Intermed-High	Med-High	S	R	S
P20-2-470	236s x CCDR	Long	Intermed-High	Med-High	S	R	S
P20-2-485	236s x CCDR	Long	Intermed-High	Med-High	S	R	S
P20-2-488	236s x CCDR	Long	Intermed-High	Med-High	S	R	S
P20-2-490	236s x CCDR	Long	Intermed-High	Med-High	S	R	S
P20-3-504	236s x CCDR	Long	Intermed-High	Med-High	R	R	S
P20-3-509	236s x CCDR	Long	Intermed-High	Med-High	R	R	S
P20-3-518	236s x CCDR	Long	Intermed-High	Med-High	Seg.	R	S
P20-3-530	236s x CCDR	Long	Intermed-High	Med-High	R	R	S
P20-3-533	236s x CCDR	Long	Intermed-High	Med-High	Seg.	R	S
P20-4-556	236s x CCDR	Long	Intermed-High	Med-High	S	R	S
P20-5-573	236s x CCDR	Long	Intermed-High	Med-High	S	R	S
P20-5-579	236s x CCDR	Long	Intermed-High	Med-High	S	R	S
P20-5-580	236s x CCDR	Long	Intermed-High	Med-High	S	R	S
P20-5-585	236s x CCDR	Long	Intermed-High	Med-High	S	R	S

[a] FRNS = Francis, CCDR = Cocodrie, S = susceptible, R = resistance, and Seg = segregating.
[b] Blank = no data.

Development of Aromatic Rice Varieties

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ABSTRACT

Interest in aromatic rice has increased with the advent of nouveau cuisine causing a rise in niche markets. 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's Aromatic Rice Breeding Program at the Rice Research and Extension Center (RREC), Stuttgart, Ark., 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 of aromatic rice varieties is very limited for the southern United States growing regions, and especially for Arkansas.

INTRODUCTION

Approximately 13.6 million metric hundredweight of milled rice were imported to the United States in the fiscal year 2011/2012 (USA Rice Federation, 2009, 2012). Of the 19% imported rice consumed domestically, 58% came from Thailand in the 2012/2013 milling year (USA Rice Federation, 2015). Thailand produces high quality Jasmine rice and India, which provides the second largest amount of imported rice, produces highly desired Basmati rice (USA Rice Federation, 2012, 2015). United States consumers are purchasing more aromatic and/or specialty rices than in previous years. It has been difficult for U.S. producers to grow the true Jasmine and Basmati varieties due to environmental differences, photoperiod sensitivity, fertilizer sensitivity, and low yields. These difficulties make aromatic rice an expensive commodity to produce. Adapted aromatic rice varieties need to be developed for Arkansas producers which meet the taste requirements for either Jasmine or Basmati.

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PROCEDURES

The aromatic rice breeding program collected parental material from the U.S. breeding programs and the USDA World Collection. Crosses were 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 2016.

RESULTS AND DISCUSSION

In 2015, 87 cross-pollinations were successfully completed to produce aromatic lines for future screening. The F_1 plants from these crosses were grown in the greenhouse during the winter to produce F_2 seed. The F_2 populations will be planted in 2016 at RREC for observation and selection.

Panicles were selected from 43 F_2 populations in 2015. The parents in these crosses were selected for their aromatic seed quality or high yield potential. Approximately 2570 F_3 lines from 43 populations were shipped to the winter nursery in Puerto Rico to advance. The harvested seed from Puerto Rico will be planted at the RREC for further observation and selection in 2016. Panicle rows from 28 F_4 and F_5 populations will be grown in 2016 for observation. Selections from these populations will be harvested and samples from the 28 populations will undergo molecular marker analysis. Lines that have the preferred markers for aroma, cooking quality, and blast resistance will be entered in yield trials in 2017.

In 2015, 151 heterozygous lines from 36 F_4, F_5, and F_6 populations were screened through marker assisted selection for aroma and amylose content. Results of the screening helped to eliminate lines which did not meet breeding program requirements. The entries which are homozygous aromatic will move forward into yield trials.

In a two-replication preliminary trial planted in 2015, 19 aromatic lines were evaluated for yield. In the Aromatic Stuttgart Initial Test, which has four replications, 19 aromatic lines were evaluated for yield and potential release. Seed from the top yielding 14 experimental lines with preferred plant types were milled and cooked in a taste test during the winter 2015. The four experimental lines 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 2016. Four aromatic experimental lines have also been entered in the 2016 Uniform Regional Rice Nursery (URRN).

In 2015, four Jasmine type experimental lines were entered in the cooperative URRN. The Arkansas mean yields for the four lines were: EXP14105, 174 bu/acre; EXP15102, 152 bu/acre; EXP15105, 127 bu/acre; and EXP15108, 151 bu/acre. Also in 2015, six experimental lines were entered in the Arkansas Rice Performance Trials. One experimental line that showed promising potential in the ARPT and URRN was EXP14105. This line originated from a cross between Jazzman and a plant introduction line. EXP14105 has excellent flavor and will continue to be examined in the ARPT and URRN in 2016. Head rows of EXP1405 will be planted for foundation seed increase in 2016.

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Rice Breeding and Pathology Technical Support

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ABSTRACT

Development of disease resistant rice is one of the most important achievements rice breeders attempt to accomplish at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC) near Stuttgart, Ark. The center's plant pathology group assists with this goal by screening rice germplasm, before the lines become advanced breeding entries, in the greenhouse and field. Breeding materials are mostly evaluated using artificial inoculation for blast and sheath blight diseases of rice at the RREC and Pine Tree Research Station (PTRS). Artificial inoculation of these pathogens on rice is essential for collecting disease severity data. Considerable amounts of disease inocula are prepared in the laboratory and applied to the plants using specific protocols. Screening for blast is conducted both in the greenhouse and the field. Screening for sheath blight is only in the field. Data from these tests are used by the breeding program either to transfer genes for resistance into adapted high yielding varieties or to advance entries for further agronomic testing. As part of the crucial responsibility for the rice extension pathology program, screening for bacterial panicle blight is largely in the field with some selected lines tested in the greenhouse. The breeding and pathology technical group, therefore, assists the extension plant pathology program not only in screening for bacterial panicle blight but with all applied research for finding answers to manage major prevailing and newly emerging diseases, including collaborative interdepartmental, industry and multi-state research endeavors.

INTRODUCTION

Disease resistance is an important element needed when developing new varieties in any breeding program. At the Rice Research and Extension Center (RREC), rice breeders and pathologists work together to develop varieties with desirable disease resistance along with pertinent agronomic traits. Disease evaluation of crops for major diseases starting in early generations has been important and is a required activity for a successful breeding program. Lines that have some potential traits but have not reached full expectation for release may possibly be used as parents to develop new varieties.

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[2] Assistant Professor, Department of Plant Pathology, Stuttgart.

Rice blast caused by *Magnaportha grisea* (T.T. Herbert) M.E. Barr is still an important disease Therefore, emphasis is given to evaluate breeding materials for both leaf and neck/panicle blast. Screening for leaf blast in the greenhouse at the seedling stage is more efficacious than field screening. However, field screening is still practiced due to the differences in controlled and natural environments. Neck/panicle blast screening is conducted only in the field where mature plants are easily maintained. Growing rice to maturity under natural conditions also allows breeders to gain beneficial knowledge about blast disease from a commercial growers' point of view.

Sheath blight (*Rhizoctonia solani* Kuhn) also remains a major disease of rice. Breeding materials are evaluated in the field at the RREC. Although there is no qualitative resistance to this pathogen, knowledge on quantitative resistance/tolerance, is greatly important to the breeding program.

Bacterial panicle blight (BPB) caused largely by *Burkholderia glumae* (Kurita and Tabei), formerly known as *Pseudomonas glumae* has shifted from being an emerging to an established disease since many of the conventional commercial rice varieties are susceptible. There are still many unanswered questions relating to the survival of this bacterium. Research is being conducted in the laboratory, greenhouse, and field to further develop practical management techniques and to obtain more understanding about this disease.

Screening for disease resistance under natural conditions may not be as reliable as it is with artificial inoculation for any of the three diseases tested at the RREC. Screening plants for blast requires desired environmental conditions prior to and after artificial field inoculations for the pathogen to sporulate and cause infection. Inoculation usually precedes a weather front that delivers dew or light rain conditions. The blast pathogen is aseptically grown on agar dishes then homogenously mixed with a sterile corn cops/ryegrass mixture for field dispersal within 24 hours. Blast inoculum preparation is done multiple times throughout the season. Sheath blight inoculum also requires massive amounts of the seed mixture to be produced; however, months of careful preparation allow it to be stockpiled for a single field application.

Bacterial isolation and purification needs a semi-selective media. The production of bacterial suspension for inoculation requires a constant supply of bacteria grown on King's B agar media. Common microbiological aseptic technique is used to produce bacterial culture plates to obtain sizable volumes of a useable bacterial suspension.

Skilled assistants/associates within the breeding/pathology support group train new employees, students, and seasonal workers in all aspects of the lab, field, and greenhouse responsibilities. This allows flexibility in assigning daily activities to timely accomplish responsibilities for the breeding and extension programs.

PROCEDURES

Evaluation of Breeding Materials for Blast Resistance in the Greenhouse

In 2015, nearly 700 entries comprised of the Uniform Rice Regional Nursery (URRN), the Arkansas Rice Performance Trials (ARPT), advanced lines, the Stuttgart Initial Tests (SIT)/Clearfield Stuttgart Initial Tests (CSIT), hybrid lines and preliminary

breeding materials were evaluated using 4 to 6 races of *M. grisea* individually per test. Seven-day old individual race isolates were washed from agar plates with a xanthan gum suspension to create a standardized spore suspension of 2.0×10^4 spores/ml. Each test was replicated three times and each individual suspension was applied at the 3- to 4-leaf growth stage (approximately 21 days after planting) using a Badger 250-2 basic spray gun. Spray inoculated plants were immediately placed in a dew chamber for about 14 hours. Disease data were collected 7 to 10 days after the plants were removed from the dew chamber and placed on a greenhouse bench. Disease evaluation was conducted 7 to 10 days after inoculation using a rating scale of 0 (no disease) to 9 (severe disease). A single comprehensive greenhouse test for only one blast race required 28 to 30 days.

Evaluation of Breeding Materials for Blast and Sheath Blight

Field testing for blast disease was replicated four times. Inoculum preparation for blast required sterilizing several hundred gallons of cracked corn (corn chops) and ryegrass seed. Several gallons of milo were also sterilized for blast inoculum. The sterilization protocol required 24 hours to process around 60 gallons for blast inoculum production. Blast races are grown on agar for 7 days before being homogenously mixed into sterile chops/milo and ryegrass seed. After mixing, the inoculum is distributed onto the test plots within 24 hours. Test plots were established on 11 June at the Pine Tree Research Station (PTRS) as hill plots surrounded by a spreader mixture of blast susceptible lines to encourage the buildup of spores for disease spread. Eight rows of corn were planted on and around the levee as a partial windbreak. Rice plants at tillering and heading were inoculated with semi-dried seed media which contained five races of the pathogen. Test plots and spreader rows were inoculated once for leaf blast at the 4-leaf stage, once at 5-leaf stage and at least twice for panicle blast starting at boot emergence. An estimation of 24 g per 6 hill plots was hand-broadcasted. A similar test was also initiated at the RREC on 8 May using entries only from the ARPT and URRN tests.

Sheath blight disease testing was replicated four times in the field. The inoculum process also required several hundred gallons of sterilized corn chops and ryegrass seed. Preparation of approximately 16 gallons of inoculum took 3 days to develop. The cultures were grown on agar for 5 days before being added to sterile chops/ryegrass seed media and allowed to grow at room temperature for a week. The sheath blight infected seed media was then air-dried and kept in paper bags until ready for field inoculation. Sanitary conditions were maintained throughout the entire process to avoid contamination. A hill plot nursery was planted on 8 May at the RREC. Air-dried inoculum that contained six isolates of the pathogen was applied to test entries at the panicle initiation growth stage. Approximately 24 g per 6 hill plots of inoculum was also hand-broadcasted. A rating scale of 0 (no disease) to 9 (severe disease) was used to collect disease severity data from all plots approximately 7 weeks after the last inoculation.

Extension Pathology

Field testing for bacterial panicle blight on the URRN/ARPT was replicated twice in hill plots that were planted on 23 May. One replication was inoculated using

a back-pack sprayer with a bacterial suspension (ca 10^6 to 10^8 colony forming units/ml) directly on the plants between boot-split to flowering stage. The other replication was observed for natural infection. Disease data were collected from all plots using a rating scale of 0 (no disease) to 9 (severe disease).

The breeding/pathology technical group also provided assistance to applied research conducted by the rice extension plant pathology program with greenhouse, laboratory, and field activities. Studies on survival of *B. glumae* in soil, seeds, or crop residues required production of over 5 gallons of CCNT, a selective media for the bacterium, to monitor its presence in colonized substrates. In addition, 4 gallons of King's B media was prepared to cultivate *B. glumae* for seed inoculations and mid-season rice plant inoculations. The study on effects of potassium on *Burkholderia glumae* conducted at PTRS required 35 pounds of Bengal seed inoculated with a bacterial suspension.

Greenhouse disease evaluation included mostly preliminary studies on various methods to artificially inoculate plants at both the seedling and adult developmental stage. Tested techniques included direct seed dip, foliar spray, syringe injection of culm, a cut leaf dip, and a soil inoculation. An investigative test of 10 entries previously tested in the 2012/2013 URRN/ ARPT with ratings of resistant (R) /moderately resistant (MR) was also conducted in both the greenhouse and field. This testing began in 2014 using 126 selected entries.

Field tests were conducted in collaboration with chemical industries that included 5 products with a total of 36 treatments for sheath blight, one early-season seedling disease containing 9 treatments and one false smut with 3 treatments. All of these tests were done in 4 replications. Inoculum for sheath blight amounted to 32,400 g to meet the needs of industry tests. The inoculum production endeavor for all tests required a substantial amount of time to prepare the various inocula and to inoculate fields at RREC and PTRS related to extension, industry, and potassium collaborative research. Disease data were collected from the respective plots and summarized for each test as each protocol required.

A false smut study was designed using the variety Roy J. A mist system was constructed to automatically apply moisture for a two-hour period during both morning and evening to create favorable conditions. A very susceptible germplasm, GP2, was planted for a border to determine the effect of disease initiation and enhancement.

Due to the lack of field protection using current fungicides, preliminary in vitro studies were conducted to check the sensitivity of the kernel smut pathogen in chemically amended agar. Colonies were estimated using a common microbiological procedure to compare the sensitivity of the fungus to triazoles and strobulin combination fungicides.

RESULTS AND DISCUSSION

As part to the breeding program, disease assessment of rice for resistance/tolerance to sheath blight, blast, and bacterial panicle blight was successfully completed for 2015. A large number of candidates rated 0 to 4 for both leaf and neck/panicle blast to the races tested. Entries tested in 2015 for sheath blight showed lower ratings than

the previous year which may be due to the dry and hot weather of late July and August along with about 50 pounds less total nitrogen applied to plants.

Field blast and sheath blight evaluations were assessed for about 1600 experimental lines and checks (Table 1). These lines include ARPT, URRN, ARPT-Imidazoline (IMI), Missouri lines, SIT-IMI, SIT, and preliminary materials from Dr. Moldenhauer, aromatics, and five long-grain advanced entries, SIT and CSIT from Dr. Sha's breeding programs. A total of 10,256 hill plots were established that included all replications. All were inoculated and evaluated for leaf and neck/panicle blast. For sheath blight, the total number lines inoculated and evaluated was 8924 hill plots including replications. In addition, the support group also does field evaluations of breeding materials for diseases under natural infection.

Of 688 experimental lines tested for leaf blast in the greenhouse, several lines rated between 0 and 4 (Table 2). Experimental lines were screened using 6 blast races. ARPT, URRN, 22 combined entries from Dr. Sha's CSIT and SIT, and aromatics were included in the tests. Four races of the six used in aforementioned tests were used for preliminary lines. In three replications, all tests included, the total number of evaluations for leaf blast in the greenhouse was 10,410.

Field evaluations for bacterial panicle blight resistance included 200 entries of the URRN and 86 entries of the ARPT in hill plots replicated twice. Of these tested entries, 27 showed low disease scores with 0 to 4 rating; 19 entries from the URRN and 8 entries from the ARPT (Table 3). Given the subset of entries with a rating of 1, some were considered to be late maturing: URRN had 5 entries and ARPT 4 entries (Table 3, Wamishe et al., 2016). These later-maturing entries may be disease escapes with their development coinciding with unfavorable weather for pathogen development and spread. In addition, 10 entries were selected for re-evaluation in the greenhouse with different types of inoculation methods after showing levels of consistent R/MR ratings (Wamishe et al., 2015).

The breeding/pathology tech support group provided an immeasurable amount of support to the success of research activities in extension pathology starting from preliminary to full-fledged applied research, collaborative research with industries and interdepartmental research along with evaluations of the breeding materials. Assistance in disease evaluations is also provided for other research departments on- and off-site upon request.

SIGNIFICANCE OF FINDINGS

The goal of the rice breeding/pathology technical support group will always be to provide support to increase the efficiency of rice breeders in developing maximum yielding cultivars with expected levels of disease resistance. The group also plays a vital role in extension plant pathology assisting with applied research. Disease evaluation remains pivotal for breeding for disease resistance. A strong applied research approach also provides dependable and practical solutions to rice producers in Arkansas and other rice-producing states. Therefore, this technical support group is actively working with the rice breeders and the extension pathology program to enhance rice productivity.

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Table 1. Number of entries rated as disease tolerant in 2015 field disease nurseries.

Test	Total entries	Sheath blight	Leaf blast[a]		Neck/panicle blast[a]	
			RREC[c]	PTRS	RREC	PTRS
		(0-5 rating[b])	(0-4 rating[b])			
ARPT	90	15	26	19	51	17
URRN	200	14	22	12	75	40
Aromatic	46	1	10	4	29	8
Missouri	100	1	NA	30	NA	18
ARPT-IMI	66	2	NA	23	NA	14
Molden-SIT	140	6	NA	71	NA	59
SIT-IMI	278	13	NA	79	NA	56
Sha-SIT	149	0	NA	89	NA	21
Sha-CSIT	149	2	NA	60	NA	20
Prelim	335	18	NA	202	NA	114

[a] Five races used in bulk for screening of entries to blast under field conditions.
[b] Rating scale of 0 (no disease) to 9 (severe disease) was used. Entries with two or more observations of a low disease rating were included.
[c] Abbreviations: RREC = Rice Research and Extension Center; PTRS = Pine Tree Research Station; ARPT = Arkansas Rice Performance Trials; URRN = Uniform Regional Rice Nursery; ARPT-IMI = Arkansas Rice Performance Trials - Imidazoline; SIT = Stuttgart Initial Tests; and CSIT = Clearfield Stuttgart Initial Tests.

Table 2. Number of entries rated as disease tolerant (0 to 4[a]) for 2015 greenhouse leaf blast testing.

Test	Entry total	IB-1[b]	IB-49	IC-17	IE-1K
URRN[c]	199	74	57	85	76
ARPT	89	27	18	30	11
Aromatic	43	26	12	20	21
Sha-SIT	22	7	6	11	10
Prelim	335	209	187	188	100

[a] Rating scale of 0 (no disease) to 9 (severe disease) was used.
[b] Data from most prominent Arkansas blast races IB-1, IB-49, IC-17 and IE-1K used for table.
[c] Abbreviations: URRN = Uniform Regional Rice Nursery; ARPT = Arkansas Rice Performance Trials; and SIT = Stuttgart Initial Tests.

Table 3. Number of entries with low bacterial panicle blight rating[a] from 2015 field evaluation.

Test	Total entries	Potential entries	Late maturity entries
URRN[b]	198	19	5
ARPT	88	8	4

[a] Rating scale of 0 (no disease) to 9 (severe disease) was used.
[b] Abbreviations: URRN = Uniform Regional Rice Nursery and ARPT = Arkansas Rice Performance Trials.
For additional information see Wamishe et al. (2016).

Studies on Rice Bacterial Panicle Blight Disease Relative to Soil Depth, Crop Residue, Dew Environment, and Potassium Levels

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ABSTRACT

Bacterial panicle blight (BPB) disease of rice is mainly caused by *Burkholderia glumae* and possibly other *Burkholderia* species. Bacterial panicle blight is thought to favor hot and dry summers particularly under extended high night temperatures. Bacterial panicle blight is one of the most threatening diseases for rice production in Arkansas and other southern rice-producing states. In 2010 and 2011 late-planted conventional rice fields were hit the hardest with BPB. Host resistance is believed to be the ultimate solution to combat this disease. Early planting, adequate rates of nitrogen fertilizer, and seeding rates have also been experimentally proven to reduce the disease incidence. The role of dew on plants and soil potassium content were tested in 2015 in relation to BPB disease development and/or the reduction of disease incidence. Research is on-going to understand the survival and infectivity of the bacteria in soil and plant residue. To be able to detect the lowest concentrations of *B. glumae* from soil, three culture media (CCNT, CPG, SMART), and three vegetables (yellow onion, carrot, celery) were tested. Among the culture media, CCNT was able to detect 3.1×10^3 cfu/g (colony forming units/gram) of soil from natural soil and 49 cfu/g soil from sterile soil. Both soils were artificially infested with a 48-h culture of *B. glumae* at 4×10^4 cfu/mL. Yellow onion was able to detect the bacteria in both sterile and non-sterile soil at a rate of approximately 1.6×10^3 cfu/g soil and in one case down to 98 cfu/g soil. Further testing of onion with *B. glumae*-infested soil is needed to further refine the technique, and tests also need to be conducted with a *B. gladioli* culture. The former is largely seedborne while the latter is believed to be more soilborne. Preliminary infectivity tests in the greenhouse and growth chamber from soil and residue were inconclusive. *B. glumae* survived in the greenhouse soil for up to four months with a substantial decrease in population size over time. The field test for infectivity of a susceptible rice cultivar by rice residue was negative. Infected residue buried or kept on the soil surface in the greenhouse tested negative on CCNT culture medium in a month, while residue in a cloth bag kept on a

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greenhouse bench for six months tested positive. Substantial blight symptom development occurred on rice panicles kept in a dew environment when sprayed with a bacterial suspension at the flowering stage. However, plants that were needle-inoculated at earlier growth stages (V4, V7, and V11) sometimes showed the visual BPB symptoms on the panicles. Rice plants incubated in dew chamber from 24 to 48 h showed an enhanced effect on panicle infection when they were needle-inoculated on the stem when the antepenultimate and penultimate leafs were emerging. Field results from 2015 annual potassium rates on incidence and severity of BPB were inconclusive. In some plots, the denser the plants, the more panicles infected. There was no significant difference between plants grown from inoculated and non-inoculated seeds. However, the amount of potassium applied significantly affected grain yield.

INTRODUCTION

Bacterial panicle blight (BPB) disease of rice is sporadic which could be due to changes in weather and environmental conditions along with multiple causal agents that may survive in seeds, soil, or crop residues. The disease is primarily seedborne and seems to favor hot summer nights. Historically, BPB was reported to cause up to 60% yield loss in susceptible rice cultivars under environmental conditions favorable for pathogen development and spread. Panicle symptoms typically develop late in the season during grain fill. In fields, infected panicles mainly have blighted florets which first appear white to light gray with a dark-brown margin on the basal third of the tissue. Later, these florets turn straw-colored and may further darken toward the end of the season with growth of other opportunistic microorganisms. Heavily infected panicles remain upright due to lack of grain fill. The bacteria most likely can be carried around by wind during rain. Predicting BPB disease occurrence and severity level before grain fill appeared difficult. The disease increased between 1995 and 2011. Historic epidemics on conventional commercial rice occurred in 2010 and 2011 both in Arkansas and other rice-producing states in the U.S. Bacterial panicle blight occurrence was relatively low in 2012 when the weather was hot and dry during the growing season. In 2013 and 2014 conditions were wet and cold for most of the growing season and there were no great issues with BPB. Although 2015 started wetter and colder than the prior two years, the latter three weeks of July and August became hot and dry increasing the apprehension of having another BPB epidemic. The hot and dry weather during this time essentially caused a lot of panicle blanking followed by various types of kernel discoloration in several rice fields of Arkansas. However, none of the panicle samples received from commercial fields in Arkansas tested positive for BPB under our laboratory testing procedure. Our research in recent years has proven that early planting, adequate seeding and nitrogen fertilizer rates reduce the incidence of BPB. Adequate water supply has been shown to increase the productivity of rice in spite of BPB incidence (Wamishe et al., 2014). To date, there are no chemical options registered in the U.S. to protect or salvage the crop from BPB disease. Efforts are being made to evaluate and develop rice cultivars with resistance. Moreover, research is underway to understand the biology of the causal pathogens and their interaction with rice plants.

This study briefly presents a single year progress report with the following objectives which were considered to be continuations of the prior research on short term BPB management options: 1) to evaluate the survival of *B. glumae* and its infectivity on rice in infected rice residues and infested soil; 2) to observe/evaluate the effect of a dew/mist on the development of bacterial panicle blight disease and a study of the association of dew in fields by tree lines and waterways; and 3) to evaluate the effect of potassium fertilizer on bacterial panicle blight disease.

PROCEDURES

Evaluation of Survival and Infectivity of *B. glumae* from Soil and Rice Residue

Survival Test for B. glumae in the Soil. Burkholderia glumae is used for our studies because our isolate collection and surveys to date indicated it is the major causal species of BPB rice disease in Arkansas. Although *B. glumae* is mainly seedborne, there is no strong evidence against it inhabiting soil or rice residue. With continuous rice cultivation on many zero grade fields in Arkansas, information on longevity and infectivity of these bacteria in the soil or residue is desired.

Preliminary greenhouse tests were carried out to determine whether *B. glumae* can survive incorporated into a sterile soil environment. Bacteria survival in drainage water was also tested by studying bacterial leaching from rice root zones where the seed inoculation was followed by rainy days after planting (2013 to 2015). Three different soils were used: field soil from the University of Arkansas Division of Agriculture's Rice Research and Extension Center (RREC) near Stuttgart, Ark., greenhouse soil mixed with vermiculite and greenhouse soil mixed with sand as 16 soil: 1:1 or 2 soil: 1:1, respectively. Approximately 2.2 lb of each soil was sterilized by pre-moistening for a couple of hours in an autoclave bag before placing in autoclave for an hour exposure time on solid cycle. Sterile soil was allowed to cool overnight prior to filling pots. Four chemically cleaned plastic pots (4-in. diam.) were filled with each of the soils. For each soil type, three pots of soil were prepared by thoroughly mixing the suspension, of bacteria (5 mL of approx. 10^9 cfu/mL *B. glumae* in salt-sugar buffer), into the soil. A non-inoculated control pot for each soil type was mixed with 5 mL sterile water. The pots were placed in open ziplock bags to collect leachate from periodic watering in the greenhouse. Initial soil sampling was done by gently pushing a drinking straw through the soil profile to obtain approx.0.5 g of soil along the depth of a pot. Top and bottom soil profiles were obtained by cutting the straw filled with soil in half. Soil was carefully removed from each portion and vortexed with 5 mL sterile water. A 100 µl aliquot of suspension was spread onto CCNT medium and incubated at 39 °C. Colony forming units were counted after 48 h of incubation. Samples were collected and tested as described above for all treatments in 4 week intervals for up to 5 months. Drainage water was also tested by streaking 0.1 mL on CCNT culture medium. Pots were irregularly watered with sterile distilled water thus allowing for the soil to dry intermittently.

A field experiment is underway to test the survival of *B. glumae* for a six-month period representing the duration from rice harvest to planting. The experiment was

started in October 2015 and it will run up to 15 March 2016. Soil is sampled and tested in monthly intervals. The procedure and results will be reported in the future.

Development of Technique to Isolate B. glumae from Soil. Comparative tests were conducted between culture media and vegetable hosts. CCNT (Kawaradani et al., 2000), CPG (Jeong et al., 2003), and SMART medium (Kawanishi et al., 2012) were selected based on previous experience and a literature search. Among vegetables, yellow onion, carrot, and celery were selected based on literature and availability. The main objective in this study was to determine the best technique for detection of a low concentration of *B. glumae* in the soil with the expectation of using the method later for *B. gladioli*. A 15 mL bacterial suspension approx.4×10^4 cfu/mL was prepared in a salt-sugar buffer (Streeter, 2007) and applied to 50 g sterilized or non-sterilized soil that were handled separately. A gram of each soil was thoroughly suspended in 10 mL of sterilized water. A 0.1 mL aliquot of soil suspension was transferred to CCNT media for each of two replications. A 1:1 serial dilution of each soil suspension was carried out 15 times (Table 1). Media were incubated for 48 h at 39℃ before scoring the plate for the characteristic cultural morphology of *B. glumae*. Fleshy onion scales and cross sectioned pieces of celery and carrot were placed on moist filter paper in a petri dish, scratched with sterile scalpel to create a wound, and then inoculated with 10 µl of either sterile or natural soil suspension. Vegetable hosts were incubated at 30℃ for 7 days until sunken water soaked lesions are formed. Tissue from the lesion was streaked back to CCNT to confirm the identity of the bacteria using morphological characteristics.

Survival Test for B. glumae in Rice Residue. Four different preliminary tests were utilized to study survival of *B. glumae* in rice residue. 1) *B. glumae* infected residue collected from artificially inoculated plants were air dried in a cloth bag on a greenhouse bench for 6 months and then tested on CCNT for *B. glumae*; 2) Seeds of Bengal sterilized with oxolinic acid were planted with infected residue mixed in a 1:1 (soil: residue by weight) ratio in the greenhouse. However, due to decaying residue, the test was modified to 2:1 (soil: residue by weight) and pots were kept in a growth chamber conducive to rice growth. From the latter test, rice plant tissues were collected at different growth stages and were tested for the presence of *B. glumae* in a polymerase chain reaction (PCR)-based assay; 3) In another test, infected rice residue was buried in pots filled with sterilized field soil about an inch deep while in another set residue was left on the surface of the soil. Pots were then watered irregularly for up to 4 months. 4) A replicated infectivity test from residue was carried out at the RREC in a field where rice was not planted in the previous 5 years. Seeds mixed with well chopped infected residue were planted by hand in a 152-ft plot with four replications. Treatments included a 1: 2, 1:1, 1:0.5 (seed: residue ratio by weight) mixture. The control plots had no residue added. A separate micro-bay was constructed for the control plots to avoid possible cross contamination of *B. glumae* through flood water.

Observations/Tests on Effect of Dew/Mist on Bacterial Panicle Blight Disease

Observation 1. Seventy rice entries had staggered planting dates based on their heading date to synchronize the timing of flowering for a mass inoculation with *B. glumae*. Due to weather-induced variability, selected rice plants were pulled out of

the field and brought to the greenhouse to create a similar pre- and post-inoculation environment. Each rice cultivar was kept in a 3-gal bucket. Plants were inoculated twice in 4-day intervals in the greenhouse following a field standard procedure (Wamishe et al., 2014). The pots were kept on the greenhouse floor to avoid drying out the panicles from the circulating air fans or lights. Due to a failure in symptom development, the pots were moved in dew chambers and incubated for 48 h. The initial purpose of this study was to evaluate rice cultivars for resistance to bacterial panicle blight under the same environment.

Observation 2. Ten selected rice entries from the 2014 Uniform Regional Rice Nursey (URRN) and Arkansas Rice Performance Trials (ARPT) that rated as moderately resistant to BPB and three control varieties, Jupiter (MR), Bengal (S), and CL151(S) were planted in a RREC field, spray inoculated at flowering and misted from boot split until grain-fill for four hours each day in late evening and early morning with a misting system constructed in the field. The initial purpose of this study was to re-evaluate the resistance level of the selected rice cultivars in the field under dew environment.

Preliminary Tests to Evaluate Effect of Dew on Bacterial Panicle Blight. A few plants of the rice variety Wells were pulled from the field at flowering stage, brought to the greenhouse and spray inoculated and then kept in dew chamber for 55 hours. The same variety in the field with a thin plant stand was heavily sprayed with *B. glumae* suspension and left under the dry-hot weather in the last week of July 2015.

A set of cultivars used in Observation 2 were pulled out and brought to the greenhouse. They were inoculated with a bacterial suspension using a syringe at the 7-lf stage and incubated in three conditions: a) in a dew chamber at night and on the greenhouse bench during the day for three days; b) in a dew chamber continuously for 48 h; and c) left continuously on greenhouse bench. Lesions were measured 7 days after inoculation.

Effects of Annual Potassium Fertilizer Rates on Rice Bacterial Panicle Blight

This is the first year of a test carried out in collaboration with Nathan Slaton on long-term plots established for potassium yield evaluations at the University of Arkansas System Division of Agriculture's Pine Tree Research Station (PTRS), near Colt, Ark. The test field consisted of five potassium fertilizer (0, 40, 80, 120, 160 lb K_2O/acre) rates in a randomized complete block design with 9 replications. *Burkholderia glumae*-inoculated seeds and non-inoculated seeds of a susceptible rice variety of Bengal were planted at a recommended seeding rate (88 lb/acre) on 23 April 2015 with a no-till planter. Plots were grown in two bays. All other inputs and irrigation were maintained in the same manner for all of the plots. Infected panicle counts per plot were collected on 11 and 12 August 2015 and statistically analyzed.

RESULTS AND DISCUSSION

Evaluation of Survival and Infectivity of *B. glumae* from Soil and Rice Residue

Survival Test for B. glumae in the Soil. Preliminary infectivity tests in the greenhouse and growth chamber from soil and residue were inconclusive due to false

positives with classical PCR-based assays in *B. glumae* presumably clean control soils. Since the control pots which contained sterilized soil were kept in the same growth chamber, the contamination probably was caused during watering and by plant-to-plant contact.

In a separate test, *B. glumae* survived in greenhouse soil for up to four months with a substantial decrease in population size over time. The greenhouse temperature ranged from 78 °F to 83 °F during the test period. *Burkholderia glumae* survived longer in the bottom and wet part of the sterilized field soil than the soil surface that was mostly dry due to the irregular watering. *Burkholderia glumae* also survived longer in pots filled with sterile field soil than the greenhouse soil. It was not clear why *B. glumae* survived longer in the field soil than in the amended soils with vermiculite and sand. However, the bacteria could more easily wash out from the sandier soil than the field soil. This observation agreed with tests in different pots where *B. glumae* colonies were captured in drained water from pots within a month of starting the experiment. This may be indicative that leaching played a role in low BPB disease incidence in experimental plots planted with inoculated seeds during past three years (2013-2015).

Residues for the following tests were collected from the very susceptible entries of URRN/ARPT plots artificially inoculated with *B. glumae* in the previous season. Infected residue buried or kept on the soil surface in the greenhouse tested negative on CCNT culture medium when tested after four months. The field infectivity test from *B. glumae*-infected residue was also negative on CCNT culture. The residue that was kept in a cloth bag on a greenhouse bench from harvest to planting for about 6 months tested positive on CCNT media, although the expected color intensity of the toxoflavin was not as strong as the initial cultures tested immediately after harvest.

Field experiments are underway to test the survival of *B. glumae* in soil from harvest to rice planting. The experiment started in October 2015 and will continue until March 2016. Monthly sampling is currently underway.

Development of Technique to Isolate B. glumae from Soil. Use of CPG another culture media and CCNT media provided recovery of *B. glumae* from a gram of inoculated soil. However, CPG allowed more contaminates to grow especially at lower dilutions of soil compared to CCNT. SMART medium failed to show any colony growth in 48 h compared to CCNT. With longer incubation time of a week, The SMART media produced distinctive bluish colonies ideal for single colony isolation and purification of *B. glumae*.

Although carrot and celery were able to detect *B. glumae* at higher levels, they were not as good as CCNT and yellow onion with lower levels. Further dilutions were tested using only CCNT and yellow onion in later repeated experiments. The CCNT media detected 49 cfu/g soil in sterile soil while detecting up to 3.1×10^3 cfu/g soil in natural soil. In natural soil, the growth of other bacteria on CCNT appeared to mask the visibility of the yellow toxin produced by *B. glumae*, a characteristic diagnostic on the medium. A pure *B. glumae* colony was transferred to a plate where natural soil contaminates existed to make observation of the capability of *B. glumae* to grow and produce the toxin. No color of the toxin was detected after 55 h incubation at 39 °C.

It is not clear from this study if growth and multiplication of *B. glumae* is suppressed or masked by other contaminates. In this study *B. glumae* formed a sunken lesion on yellow onion at concentrations of approx. 1.6×10^3 cfu/g soil. When a small tissue of onion from the sunken area was transferred to CCNT after 7 days of incubation at 30℃, bacterial growth and typical *B. glumae* cultural characteristics were shown. Although, the vegetable host system needs more work to refine the technique, this preliminary finding suggested the potential use of onion to compliment CCNT medium to detect *B. glumae* from field soil.

Survival Test for B. glumae in Rice Residue. Results of the four preliminary tests are summarized below: 1) Infected rice residue kept in cloth bags in a greenhouse tested positive for *B. glumae* after six months. However, there was a substantial decline in the *B. glumae* population on CCNT medium compared to the initial density; 2) Seeds of Bengal sterilized with oxolinic acid and planted in infected residue mixed in a 1:1 (soil: residue) ratio in the greenhouse showed decay which resulted in poor germination. The experiment was modified with oxolinic acid-treated seed planted in 2:1 (soil: residue) pots that were kept in a growth chamber. In this test, most of the plant samples collected at different stages tested positive for the bacteria. However, plants from the residue-free control pots also tested positive for *B. glumae* rendering inconclusive results; 3) Infected residue left on the surface or buried in the soil in a greenhouse pot experiment tested negative for *B. glumae* after four months; 4) Bengal seeds (susceptible to BPB) planted and mixed with infected residue showed no symptom of BPB when grown in a field at the RREC in 2015. RandomLy picked florets from random panicle samples also tested negative on CCNT culture media. Sample collection and testing for the field experiment on the survival of *B. glumae* is underway. Sampling is done in a monthly interval running from October 2015 through 15 March 2016 representing the duration from rice harvest to planting. A report will be ready upon completion of the test. Although *B. glumae* is mainly seedborne, there is no strong evidence for its lack of ability to inhabit soil or plant residue. With the continuous rice cultivation practice particularly in zero grade rice fields of Arkansas, information on longevity and infectivity of these bacteria from the soil or residue will be useful because currently *B. glumae* is the primary cause of BPB disease of rice.

Observations/Tests on Effect of Dew/Mist on Bacterial Panicle Blight Disease

Observation 1. Ninety seven percent of the 70 entries that did not show symptoms of BPB 10 days after the first spray inoculation showed differing levels of BPB symptoms during the 48 hours of dew incubation.

Observation 2. Except for the hybrid rice included in the test, 50% of the entries that were selected as moderately resistant shifted to moderately susceptible when placed in the artificially elongated dew period.

Preliminary Tests to Evaluate Effect of Dew on Bacterial Panicle Blight. In 2015, a few plants of rice cultivar Wells that were spray-inoculated with *B. glumae* suspension at flowering and kept in a dew chamber for 55 hours resulted in fully failed

grain with severe symptoms of BPB disease. In contrast, the same variety inoculated in a similar way and on the same day in a field test during the dry week of July continued filling grains. Bacterial panicle blight symptoms were not clear until two weeks after the inoculation date.

The lesion lengths of the 13 rice cultivars which were needle-inoculated at the 7-lf stage and kept intermittently or continually in a dew chamber for up to 3 days did not show substantial difference from those kept on the bench.

There are clear indications that moisture in the form of dew, mist, fog, and possibly rain are an important factor in a BPB disease epidemic. The second observation and the two preliminary tests described above, are in agreement with the field observation in 2012 where the season was hot and dry and BPB was expected in large scale. However, only two commercial fields, one planted with Jazzman 2 and the other with CL111 were reported. In both fields, BPB incidence was higher close to a waterway or tree lines suggesting the positive role of longer dew periods on BPB incidence and severity.

The fact that experimental plots established in an open field and planted with artificially inoculated seeds revealed nearly 100% BPB incidence in a susceptible rice cultivar, Bengal, within a week after the tropical storm Isaac passed through in 2012 strongly supports the role of wind with rain enhancing the panicle symptoms and/or spreading of the bacteria within the plots and across the bay. There was severe BPB on the non-inoculated rice cultivar Wells on the west side of these seed inoculated plots. Wind direction at the time of the storm was largely from east to west.

Effects of Potassium Fertilizer Rates on Rice Bacterial Panicle Blight

Five potassium fertilizer rates (0, 40, 80, 120, 160 lb K_2O/acre) were used in this test. There was significant difference in yield response to annual K_2O fertilizer rates (Slaton, 2015, pers. comm.). Plots with lower potassium rate had a scant canopy compared to those that received higher rates showing a positive relationship between canopy cover and yield. Incidence of BPB disease increased as rice canopy increased up to the 80 lb K_2O/acre rate, and at higher potassium rates the disease was reduced and then became erratic (Fig. 1). Previous studies on the effect of nitrogen fertilizer and seeding rates showed that the rice canopy increased with increased nitrogen and excessive seeding rates (Wamishe et al., 2014; 2015). Likewise, BPB incidence also increased. It makes sense that plots receiving low rates of potassium had a lower plant stand resulting in limited BPB incidence. Bacterial spread from plant to plant can be limited in thin rice plots. It also is plausible that higher potassium rates showed relatively low BPB incidence. Well managed rice plants with adequate levels of nutrition, particularly potassium, were proven to increase rice plants' tolerance to disease. Data from 2015 were somewhat erratic in BPB response to potassium fertilizer rates and need to be repeated before any conclusions can be reached. Moreover, there was no significant difference in disease incidence due to seed inoculation with *B. glumae*. It was possible that the bacteria may have been washed down by rain that was frequent before germination. The field experiment will be repeated at least twice to clearly learn the relationship between BPB rice disease and potassium fertilizer rates.

SIGNIFICANCE OF FINDINGS

Managing bacterial panicle blight of rice is very important to reduce potential yield losses. With lack of resistance in current commercial rice cultivars and absence of chemical options, cultural management options are immensely important to rice producers. To effectively manage the disease, understanding the biology of the pathogen and its host is inevitable. Cultural management options can always be integrated with host resistance. These studies and findings appear interesting both from a scientific and practical point of view.

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Table 1. Serial dilutions and approximate colony forming units of *Burkholderia glumae* for inoculated soil.

Dilution	Approx. cfu/g soil	Dilution	Approx. cfu/g soil
99 OD	400,000	1/256	1600
1/2	200,000	1/512	781
1/4	100,000	1/1,024	391
1/8	50,000	1/2,048	195
1/16	25,000	1/4,096	98
1/32	12,500	1/8,192	49
1/64	6200	1/16,384	12
1/128	3100	1/32,768	6

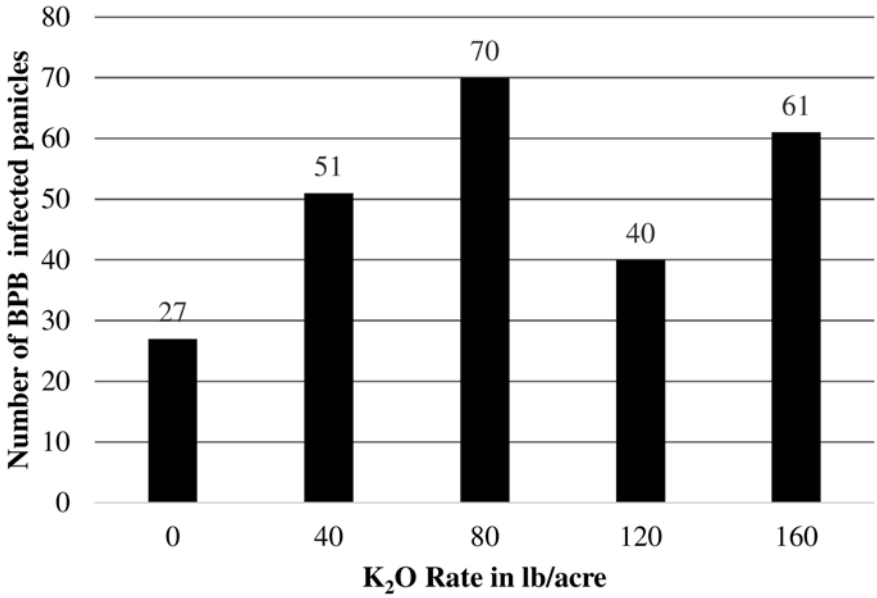

Fig. 1. Number of bacterial panicle blight diseased panicles found in the plots of the rice cultivar Bengal for varying soil potassium levels for both the inoculated and non-inoculated Bengal seed.

Monitoring Bacterial Panicle Blight Disease of Rice and Germplasm Evaluation for Resistance in Arkansas in 2015

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ABSTRACT

Rice is a major cereal crop that contributes significantly to global food security. Rice can be affected by both abiotic and biotic stresses. Rice bacterial panicle blight (BPB) has been recognized as one of the major biotic factors that can cause severe yield loss in southern U.S. rice-growing states and several other rice-growing countries. Cultural practices such as early planting with adequate seed and nitrogen fertilizer rates have been experimentally shown to reduce the disease incidence. To date, chemical options are not available for use in the U.S. None of the current conventional commercial rice cultivars appear to have complete resistance to BPB. Hybrid rice and Jupiter have shown moderate resistance under field conditions in the epidemic years of 2010 and 2011. Breeding for disease resistance requires continuous efforts by breeders to enrich their gene pools to effectively tackle yield robbing problems. In the past few years, research efforts have been focused on understanding the causal bacterial species of panicle blight and evaluating rice for resistance to BPB. In 2015, a total of 165 panicle samples that were either fully or partially blank with or without floret discoloration were collected from 9 rice-producing counties. Samples were collected largely, from the Uniform Regional Rice Nursery (URRN), Arkansas Rice Performance Trials (ARPT), or Producer Rice Evaluation Program (PREP) across Arkansas. Of the165 field samples collected, 72 samples were considered positive for *B. glumae* visually on CCNT culture medium. However, the molecular approach using classical polymerase chain reaction (PCR) with specific primers confirmed only 45 as positive to *B. glumae*. When these 45 isolates were tested with a *B. gladioli* primer, none tested positive for *B. gladioli* suggesting *B. glumae* as the major causal agent of BPB in these samples. Two rice germplasm nurseries, namely ARPT and URRN consisting of 90 and 200 entries, respectively were evaluated for BPB using artificial inoculation in an experimental field at the University of Arkansas System Division of Agriculture's Rice Research

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and Extension Center (RREC) near Stuttgart, Ark., in 2015. A 0 to 9 disease rating scale was used where 0 is no disease and 9 severe disease with blank panicles. Based on the reference reactions of Jupiter (MR) and Bengal (S), 27 entries were categorized as R (resistant), 34 MR (moderately resistant), 36 MS (moderately susceptible), 126 S (susceptible), 62 VS (very susceptible), and none were rated zero (immune/highly resistant). Late-maturing rice entries appeared relatively clean and were placed in the resistant category. However, further investigation is required to ensure true resistance to BPB in these late-maturing rice entries. False resistance response or disease escape can possibly be due to the unfavorable weather conditions during and after inoculation as the season tapered off.

INTRODUCTION

Rice constitutes the staple diet for more than 50% of the world's population in terms of cultivation and consumption (FAO, 2012). It is part of the everyday diet of many households. Rice production and consumption are concentrated in Asia, other parts of the world such as South America, Africa, Australia, some parts of Europe, and southern United States (FAO, 2012). Rice production is constrained by many abiotic and biotic factors among which bacterial panicle blight (BPB) has been ranked recently as a major threat (Shahjahan et.al., 2000).

Bacterial panicle blight is caused by the gram-negative bacterial pathogens *Burkholderia glumae* and *B. gladioli* and probably a couple others. Symptoms include panicle discoloration, grain rot, and sterile florets. Bacterial panicle blight is favored by prolonged high night temperatures during the heading and flowering stages (Nandakumar et al., 2009). *B. glumae* is considered by and large as seedborne bacterium. It produces yellow-colored phytotoxin (toxoflavin) that has been proved to be its major virulence factor (Sato et al., 1989). To date, complete rice host resistance for BPB has not been reported. Oxolinic acid is the only known commercial chemical agent for controlling this disease. However, chemicals such Oxolinic acid and Kasugamycin used in some countries are not labeled for U.S., and reports on antibiotic resistance limits their usage (Hikichi et al., 2001). Our study in 2015, therefore, focused mainly on the distribution of BPB in nine rice-producing counties of Arkansas and rice germplasm evaluation for BPB resistance under field condition using artificial inoculation. Results from molecular marker and greenhouse evaluations will be reported once tests are completed.

PROCEDURES

Isolation and Identification of *Burkholderia* Species from Arkansas Rice

One hundred sixty-five rice panicle samples that either showed some level of blanking or brown floret discoloration were collected from nine rice-growing counties in Arkansas. The counties included: Prairie, Arkansas, Lincoln, Desha, Clay, Mississippi, Craighead, Jackson, and Woodruff. Samples were mainly collected from the counties with field plots of the Uniform Regional Rice Nursery (URRN), Arkansas Rice Perfor-

mance Trials (ARPT), and Producer Rice Evaluation Program (PREP). About 100 florets from each sample were randomly picked and kept at 4 °C in a coin envelope until plated on a culture medium. CCNT, a semi-selective medium for *B. glumae* (Kawaradani et al., 2000) was used to plate the seeds. Cultures were then incubated at 39 °C for 48 h in the dark. Bacterial colonies that showed similar morphology to *B. glumae* on culture were isolated and purified. DNA was extracted from pure cultures of each isolate and a polymerase chain reaction (PCR)-based method was used to identify the isolate with *B. glumae* and *B. gladioli* specific primers (Yukiko et al., 2006).

Evaluation of Rice for Resistance Against Bacterial Panicle Blight Disease

In 2015, the ARPT and URRN consisting of 90 and 200 entries, respectively, were evaluated for BPB. The entries were tested using artificial inoculation under field conditions at the RREC following the procedure in Wamishe et al. (2013). Hill plots were used to plant two replicates of 290 lines interspaced with Jupiter and Bengal after each 10 entries. Another bay was planted similarly to serve as a non-inoculated check. Jupiter and Bengal were included as known references for moderately resistant and susceptible reactions to BPB, respectively. Inoculation for each entry was carried out between the boot-split to flowering growth stage twice in an interval of 4 days to reach the panicles on both the primary and secondary tillers. Spray-inoculation was targeted to the panicles. A 48-h old *B. glumae* culture grown on King's B medium at 39 °C was used to produce the pathogen suspension. The suspension was ~10^6 to 10^8 cfu/mL (colony forming units/milliliter). Disease reactions were evaluated four weeks after the last inoculation using a 0 to 9 scale, where 0 is no disease and 9 is severe disease (Table 1).

RESULTS AND DISCUSSION

Isolation and Identification of *Burkholderia* Species from Arkansas Rice in 2015

Of 165 field samples collected, 72 samples were considered positive for *B. glumae* visually on CCNT culture medium. However, the molecular approach using PCR with specific primers confirmed only 45 as positive for *B. glumae*. When tested with a *B. gladioli* primer, none tested positive for *B. gladioli* indicating *B. glumae* was the major causal agent of BPB in Arkansas. Based on this study, the largest proportion of samples tested negative for *B. glumae* suggesting that there were other causes for panicle blanking and discoloration during the hot and dry weeks of July and August in 2015. These results also suggest that molecular technique are useful in verifying visual and cultural identification of *B. glumae*.

Evaluation of Rice for Resistance Against Bacterial Panicle Blight Disease

None of the 290 rice entries tested were immune to BPB disease under field conditions using artificial inoculation. Based on the reference reactions of Jupiter (MR) and Bengal (S), 27 entries were categorized as R (resistant), 34 MR (moderately resistant), 36 MS (moderately susceptible), 126 S (susceptible), and 62 VS (very susceptible)

(Table 2). Late-maturing rice varieties appeared relatively clean, and were placed in the resistant category (Tables 3 and 4). However, further tests are required to ensure true resistance to BPB in late-maturing rice. Disease escape or a false resistance response can possibly be due to the unfavorable weather conditions during and after inoculation as the season tapered off. On the other hand, as reported in Pinson et al. (2010), late maturity may be a confounding factor for genetic resistance to *B. glumae*. Further testing with molecular markers coupled with greenhouse testing is recommended for evaluation of genetic resistance to *B. glumae* for late-maturing rice. Note that the late-maturing commercial rice cultivar Roy J was susceptible to BPB during the epidemic years. However, in this test, Roy J was resistant indicating that it was a possible outcome of environmental effects. Overall, the resistance groups from this and previous seasons are encouraging for the identification of resistant rice cultivars.

Results from other on-going laboratory molecular marker and greenhouse resistance evaluation activities will be presented at the completion of the tests.

SIGNIFICANCE OF FINDINGS

Rice resistance to BPB would provide long-term control in years of increased disease pressure and thus improve yield. Development of a better toolbox to evaluate genetic resistance remains to be an important priority for combating BPB disease in rice. The preliminary surveys of *Burkholderia* species across Arkansas are encouraging suggesting that the major causal organism is primarily one species of *Burkholderia*. Extensive surveys with different molecular markers will be needed to evaluate diseased plants from commercial rice fields particularly in epidemic years. Efforts to understand virulence, pathogenicity, and epidemiology of the *Burkholderia* pathogen must continue in order to identify more effective control means to manage BPB.

ACKNOWLEDGMENTS

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Table 1. The 0 to 9 disease rating scale used to evaluate rice reactions to bacterial panicle blight under field conditions sprayed with *Burkholderia glumae* between late-boot to flowering stage of rice development.

0-9 scale	Reaction group	0-9 scale	Reaction group
0	Immune	5	Moderately resistant (MR)
1	Resistant (R)	6	Moderately susceptible (MS)
2	Resistant (R)	7	Susceptible (S)
3	Resistant (R)	8	Susceptible (S)
4	Moderately resistant (MR)	9	Very susceptible (VS)

Table 2. Number of rice entries grouped in different relative resistance categories for rice bacterial panicle blight disease using a 0 to 9 rating scale in 2015.

Reaction group	URRN[a]	ARPT	Total
Highly resistant	0	0	0
Resistant	19 (8)[b]	8 (6)	27 (14)
Moderately resistant	30	4	35
Moderately susceptible	32	4	36
Susceptible	84	42	126
Highly susceptible	33	29	62
Total	198	88	186

[a] URRN = Uniform Regional Rice Nursery; ARPT = Arkansas Rice Performance Trials.
[b] Numbers in parentheses indicate number of late-maturing entries.

Table 3. Rice entries in the resistant group from Uniform Regional Rice Nursery (URRN) to bacterial panicle blight (BPB) disease of rice in 2015.

Entry no.	Accession	BPB disease score	Maturity
URRN-20	MRMT	2	
URRN-23	RU1503023	1	
URRN-25	RU1402125	2	
URRN-33	RU1304156	1	
URRN-35	RU1304122	2	
URRN-61	RU1501061	2	
URRN-63	RU1003153	2	
URRN-68	RU1502068	2	
URRN-71	RU1502071	2	
URRN-79	ROYJ	1	Late
URRN-80	MM14	1	Late
URRN-91	RU1502091	1	
URRN-92	RU1503092	2	
URRN-108	RU1501108	2	Late
URRN-126	RU1503126	2	Late
URRN-139	RU1501139	1	Late
URRN-160	TGRT	1	Late
URRN-161	RU1401161	1	Late
URRN-194	RU1504194	2	Late

Table 4. Rice entries in the resistant group from Arkansas Rice Performance Test (ARPT) to bacterial panicle blight (BPB) disease of rice in 2015.

Entry no.	Accession	BPB disease score	Maturity
ARPT-16	RTCLXL729	1	
ARPT-17	RTCLXL745	2	
ARPT-42	RU1501139	1	Late
ARPT-47	STG11F3-04-065	1	Late
ARPT-52	STG11P-23-073	1	Late
ARPT-56	STG12L-48-213	2	Late
ARPT-57	RU1501047	1	Late
ARPT-60	STG12L-47-256	2	Late

Understanding Autumn Decline, Evaluating Rice Varieties for Resistance, and Identifying New Strategies to Reduce the Phenomenon in Problematic Rice Fields

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ABSTRACT

Autumn decline and hydrogen sulfide toxicity have similar symptomology and are often referred to as the same thing even if they are two different problems in rice fields. Symptoms include black root rotting with stunted and yellowish rice foliage starting as early as two weeks following permanent flood establishment. To understand the primary causes of autumn decline in Arkansas, tests on redox of different soils that have had autumn decline problem are underway. To search for practical methods to prevent or reduce the problem, preliminary greenhouse pot experiments have been underway to test three oxidizing agents and two bio-products (microbial oxidizers) using field soils from two different fields in Woodruff County. To evaluate rice for degree of resistance or tolerance to autumn decline under field conditions, a Producers' Rice Evaluation Program field trial consisting of 20 commercial cultivars was planted in 2015. To prove the effect of soil drainage on autumn decline severity and cultivar survival rate, greenhouse tests were carried out. Although inconsistent across replications, the field study indicated various levels of susceptibility among the cultivars tested. From the cultivar test data, a rating matrix scale was developed that combined root blackening and crown blockage or discoloration. Greenhouse tests on practical methods to alleviate the problem were not conclusive. Preliminary greenhouse soil drainage tests showed new root growth within four days. Since this is the first study year, results are considered too premature to draw conclusions.

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INTRODUCTION

Autumn decline and hydrogen sulfide toxicity, also referred as akiochi, have similar symptomology and are often referred to as the same thing even though they are two different problems in rice fields. Symptoms include black root rotting with stunted and yellowish rice foliage starting as early as two weeks following permanent flood establishment. The problem is often most severe where cold well water first enters a rice field and may spread throughout the field, except on levees. The phenomenon was reported in Arkansas in a limited number of fields in 2004 (Delta Farm Press, 2004; Wilson and Cartwright, pers. comm.). However, there were several reports of autumn decline across the state of Arkansas in 2012, 2013, and 2014, and even more in 2015. Although the problem may be aggravated in the anaerobic/flooded situation, there is no clear understanding of why this phenomenon is occurring in different soil types across several rice-growing counties in Arkansas. Observations have shown fields having a clay loam soil texture are more prone to the autumn decline phenomenon than others commonly cropped to rice. The root rotting symptoms often start a few weeks after flood establishment and become progressively worse throughout the season if unmitigated. In situations where root rotting is severe, fungi grow into the crown which limits function of the whole root system and prevents translocation of water and nutrients from the soil to the plant. In moderate to severe cases, tillers break off easily and plant death may occur rapidly leading to significant yield losses. Ongoing field and greenhouse investigations that started in 2015 have the following objectives: 1) to understand the primary causes of autumn decline in Arkansas; 2) to search for practical methods to prevent or correct the root blackening and rotting associated with autumn decline; 3) to evaluate the degree of resistance or tolerance of common rice cultivars to autumn decline under greenhouse and field conditions; and 4) to evaluate the effect of soil drainage (the current preventative/rescue strategy) on autumn decline severity and cultivar survival rate.

PROCEDURES

To understand the primary causes of autumn decline in Arkansas, five fields known to have a history of autumn decline were identified, with varying levels of disease history and severity. Soil samples from these locations have been collected, sterilized and flooded to study redox differences between sterilized and non-sterilized soils across soil types and locations. Redox potential is the inherent tendency of a compound to act as an electron donor or electron acceptor as defined by Fuhrmann (1999). This portion of the research is focused on identifying the soil chemical and physical attributes that contribute to the occurrence of autumn decline. Development of protocols to identify areas/fields that are prone to autumn decline and preventative measures that are more effective in preventing yield loss associated with the disease are anticipated.

To search for practical methods to prevent or correct the root blackening and rotting associated with autumn decline, preliminary greenhouse pot experiments have been underway to test three oxidizing agents and two bio-products (microbial oxidizers) using field soils from two different fields in Woodruff County. Both fields were known

to have a history of autumn decline in previous years. Soil from the Hillemann, Ark., area appeared light in color with visually noticeable iron content and was collected at the beginning of October 2015, approximately two months after rice crop harvest. Soil from the Hunter area appeared darker in color and was collected at the end of October 2015, about a month after the soybean harvest. The first experiment was conducted using the soil collected from the Hillemann area. The second experiment is currently running using the soil collected from Hunter area. Big plant residue materials were sieved out and removed from the soil prior to the initiation of the trials. In both experiments, a very susceptible rice cultivar Mermentau was used based on data collected from the 2015 field test. Taking into account the delayed and erratic start of symptoms in the first and second experiments, pots for the third experiment were flooded for three weeks before planting. CL151, another known susceptible variety for autumn decline was used for the third experiment. Pre-germinated seeds were planted in muddy soil and pots were left wet to keep the soil somewhat anaerobic. Pots were flooded to about a 2-in. depth after the seedlings received their first nitrogen application at 5-lf stage and kept flooded. All experimental pots were kept flooded throughout the experiment with refrigerated water at 4 °C until flowering. Treatments included: 1) a product which claimed to have sulfur-philic anaerobic bacteria; 2) a product which claimed to have photosynthetic and sulfur-philic bacteria; and three other oxidizing compounds, namely KNO_3, H_20_2, and $KMNO_4$. Two control treatments were included, one with continuous flood and the other with intermittent flushing. The test was designed to be conducted in three replications. The test will be repeated at least twice following the procedure that renders the best desired symptoms. Field tests will be conducted possibly in 2017 using products that may provide the best protection from autumn decline.

To evaluate rice for degree of resistance or tolerance to autumn decline under field conditions, a Producers' Rice Evaluation Program (PREP) field trial consisting of 20 commercial cultivars was planted in 2015 (Table 1). The trial was planted in four replications in a field that had a history of autumn decline near Hillemann, Ark., in Woodruff County with a plot size of 8 rows on 7-in. spacing, 15 ft in length. When the early maturing cultivars were flowering, roots were pulled from the north-side outer row of all plots, washed immediately, and rated for both root and crown discoloration using a 0 to 5 and 0 to 9 rating scale, respectively. From these data, a disease matrix was developed that combined the two ratings for the length of time they were under flood. Note that these cultivars may not have similar heading and maturity dates. The later the cultivar, the more flood exposure duration. The rating scale will be evaluated in the years to come in both greenhouse and field studies.

To evaluate the effect of soil drainage on autumn decline severity and cultivar survival rate, a preliminary greenhouse experiment was conducted back in 2013 using field soil from the Hunter area in Woodruff County. The soil was collected immediately prior to harvest. Pre-germinated seeds of 10 cultivars were planted without removing the rice residue and pots were kept flooded with refrigerated water. Plants were drained around the vegetative stage V11 (Counce et al., 2000), left to dry for four days and then re-flooded. Similar greenhouse tests and different field tests will be carried out in the upcoming years.

RESULTS AND DISCUSSION

Some tests are currently being conducted to understand the primary causes of autumn decline in Arkansas, and data was not available at the time of this report.

The first experiment using iron-rich soil from Hillemann, Ark., produced up to 50% blackening in some of the plants from continuously flooded control pots. Although there were some indications of activity to the tested products, it appeared that the soil and rice plants were not exposed to anaerobic conditions enough to give uniform symptoms to all plants in the control. Plants were pulled to collect data after the rice reached the flowering stage. Since the soil appeared to have high iron levels, and such soils may require a longer duration of flooded conditions to reach an anaerobic state, results from the first test are considered inconclusive. The second and the third experiments were underway during the time of this reporting.

The field study to evaluate degree of resistance or tolerance of common rice cultivars to autumn decline showed potential differences among cultivars. Rating information from this study was used to select potentially more susceptible cultivars for further evaluation in greenhouse trials. However, due to inconsistencies in some of the cultivars within replications, data are not shown for this reporting. The inconsistency within replications maybe due to variation in flood depth within the field.

The fact that autumn decline in this field was recorded using two rating scales (a 0 to 5 and a 0 to 9) it was deemed necessary to develop a matrix index that best described the severity level in each cultivar for comparison. Twenty rice cultivars were evaluated in the field trial (Table 1) using descriptive rating scales (Table 2) to quantify the extent of damage that was then summarized as a matrix scale (Table 3). In developing the rating matrix for autumn decline, crown discoloration has been given double the weight compared to root blackening due to its higher effect on grain yield loss. Observations and experiments have shown crown discoloration as irreversible damage compared to the often reversible symptom of root blackening.

Preliminary tests in 2013 indicated both root blackening and crown discoloration as reproducible in a greenhouse using soils with a history of autumn decline. Ten cultivars tested in a greenhouse indicated cultivar differences in tolerance (data not shown). Root vigor and oxidation power of roots may play a role in cultivar tolerance. However, the experiment needs to be repeated to confirm these results.

In a preliminary greenhouse experiment to evaluate the effect of soil drainage on autumn decline severity and cultivar survival rate, pots were drained and left to dry for four days. They showed new root development just above the base of the crown. These experiments need to be repeated in the greenhouse and tested in the field to determine the length of time required for new roots to grow and root colors to reverse in different soils types and environments/locations. Until then, these will be considered premature results even though they are in agreement with field observations which showed new root growth and the positive effect of draining and drying out the soil.

The idea behind the drain and dry strategy is to allow oxygen into the rhizosphere to reaerate the soil and prevent hydrogen sulfide production. However, this strategy is not compatible with limited water resources and can be costly, especially in large fields

where draining and re-flooding each take several days to complete. As a result the risk of yield loss due to drought stress could be high. Therefore, searching for alternative management options would be very beneficial.

SIGNIFICANCE OF FINDINGS

From 2012 to 2015 root blackening and crown rotting, known as autumn decline or often referred to as hydrogen sulfide toxicity of rice, appeared to be increasing compared to the eight previous years. Although hydrogen sulfide toxicity is considered the cause, a better understanding of this phenomenon is needed. Autumn decline and hydrogen sulfide toxicity are often referred to as the same thing even if they are two different problems in rice fields. In some fields, draining surface flooded water improved the situation. However, in other fields the drain and dry approach did not improve the situation enough to salvage the crop. A better understanding of this problem would permit growers to make the best decisions possible to avoid losses due to the failure of the drain and dry strategy. Additionally, the drain and dry approach does not work if a field is not a manageable size. Knowledge of cultivars' susceptibility/intolerance and the discovery of additional management options could have prevented the significant losses that have occurred to some rice fields in previous seasons.

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Table 1. Rice cultivars tested for autumn decline/hydrogen sulfide toxicity resistance/tolerance in a field in Hillemann, Ark., at Woodruff County in 2015.

Rice cultivars tested							
1	LaKast	6	CL111	11	CL153	16	RTXL753
2	Roy J	7	CL151	12	CL172	17	RTXL760
3	Taggart	8	CL163	13	CLX1102	18	Titan
4	Mermentau	9	CL271	14	RTCLXL729	19	Diamond
5	Jupiter	10	CL272	15	RT CLXL745	20	MSX4077

Table 2. Rating scales used to rate crown discoloration and root discoloration in cultivars grown in soil with history of autumn decline/hydrogen sulfide toxicity at Hillemann, Ark., in 2015.

0 to 9 scale	% Crown length discolored[a]	0 to 5 scale	% Root mass blackened[a]
	(%)		(%)
0	0	0	Clean as in levee roots
1	10	1	10
2	20	2	25
3	30	3	50
4	40	4	75
5	50	5	75 or >
6	60		
7	70		
8	80		
9	90 or >		

[a] Roots need to be washed well and rated immediately, up to 10 root crowns need to be examined. Numbers shown under % columns refer to range of estimate. For instance: 10 refers to discoloration percentage up to 10.

Table 3. Matrix to rate incidence and severity of autumn decline/hydrogen sulfide toxicity in rice cultivars.

			% Root blackening aligned with a 0 to 5 scale					
% Crown infection	0 to 9 scale	2X (0-9)[a]	0 0	10% 1	25% 2	50% 3	75 4	>5 5
0	0	0	R	R	R	MR	MR	MS
10	1	2	R	MR	MR	MS	MS	S
20	2	4	MR	MS	MS	S	S	VS
30	3	6	MS	S	S	VS	VS	VS
40	4	8	S	VS	VS	VS	VS	VS
50	5	10	VS	VS	VS	VS	VS	VS
60	6	12	VS	VS	VS	VS	VS	VS
70	7	14	VS	VS	VS	VS	VS	VS
80	8	16	VS	VS	VS	VS	VS	VS
90	9	18	VS	VS	VS	VS	VS	VS

[a] The 0-9 scale was multiplied by 2 to give more weight to crown infection as it is the more serious and irreversible problem than the root blackening. Root crown is the upper part of the main root system.

Efficacy of Selected Insecticides for Control of Rice Stink Bug, *Oebalus pugnax,* in Arkansas, 2015

H.M. Chaney[1], G.M. Lorenz[2], N.M. Taillon[2], W.A. Plummer[2], and J.L. Black[2]

ABSTRACT

A trial was conducted to evaluate selected insecticides for the control of rice stink bug, *Oebalus pugnax*. Results indicated that all treatments reduced rice stink bug below the untreated check up to 13 days after application.

INTRODUCTION

Rice stink bug is a common and important pest in Arkansas rice. In the spring, rice stink bugs feed and reproduce on a wide range of wild grasses. This enables the rice stink bug to reproduce and increase in numbers before cultivated host plants are available. Rice stink bugs normally do not occur in rice fields until heading has begun, but may occur earlier if heading of wild grasses is present in or around field edges. Early feeding from pre-fertilization through early milk stage causes the heads to blank or abort resulting in yield reduction. Feeding during the milk-to-soft dough stage results in kernel shrinkage or slight discoloration commonly referred to as "pecky rice" (Johnson et al., 2002). This can result in deductions in quality or grade. The use of insecticides gives producers the ability to lower rice stink bug numbers. When populations are at moderate levels, a single insecticide application may be used to control rice stink bugs. When populations are high, multiple applications may be required to achieve control (Plummer et al., 2015; Thrash et al., 2012). Finding alternative insecticides is necessary to reduce potential for resistance. A trial was conducted to evaluate current and potential foliar treatments for control of rice stink bug.

PROCEDURES

The trial was conducted near Colt, Ark., at the University of Arkansas System Division of Agriculture's Pine Tree Research Station. Plot size was 15 ft × 35 ft in a

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randomized complete block design with four replications. Foliar treatments included: Endigo ZCX (5 oz/acre and 6 oz/acre); Karate Z (2.56 oz/acre); Tenchu (9 oz wt/acre); Strafer (3.5 oz/acre); and A21120A (15.5 oz/acre). 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/acre, at 40 psi. Insect counts were taken at 3, 7, 11, and 13 days following treatment by taking 10 sweeps per plot with a standard sweep net (15-inch diameter). Data was 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 3 days after application (DAA), all treatments reduced rice stink bug numbers below the UTC; Endigo ZCX (6 oz/acre) had fewer rice stink bugs than A21120A, Strafer, and Endigo ZCX (5 oz/acre) (Fig. 1). By 7 DAA, rice stink bug numbers increased in the UTC; however in all treatments, rice stink bug numbers went down from 3 DAA; Endigo ZCX (6 oz/acre) and A21120A had fewer rice stink bugs than all other treatments (Fig. 2). At 11 DAA, all treatments had fewer rice stink bugs than the UTC; A21120A had fewer stink bugs than all other treatments; Endigo ZCX (5 oz/acre) had fewer stink bugs than Karate Z and Tenchu (Fig. 3). At 13 DAA, all treatments had fewer stinkbugs than the UTC but no difference between treatments was observed (Fig. 4).

SIGNIFICANCE OF FINDINGS

Rice stink bug is one of the most damaging pests in Arkansas rice, it not only affects yield but can affect the quality of the rice. We will continue to conduct studies to find economic ways for growers to control rice stink bug.

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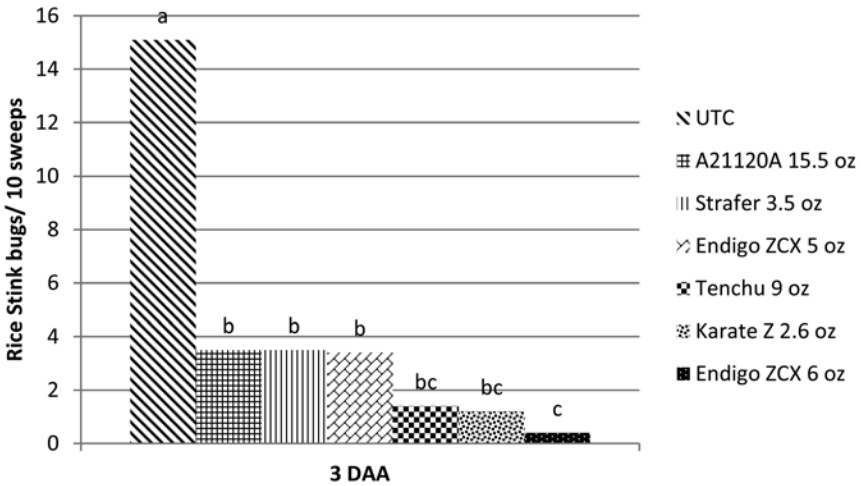

Fig. 1. Rice stink bug counts taken 24 August, 3 days after application (DAA). UTC = untreated check. Means followed by same letter do not significantly differ (*P* = 0.10, Duncan's New Multiple Range Test). Mean comparisons performed only when analysis of variance Treatment P (F) is significant at mean comparison observed significance level.

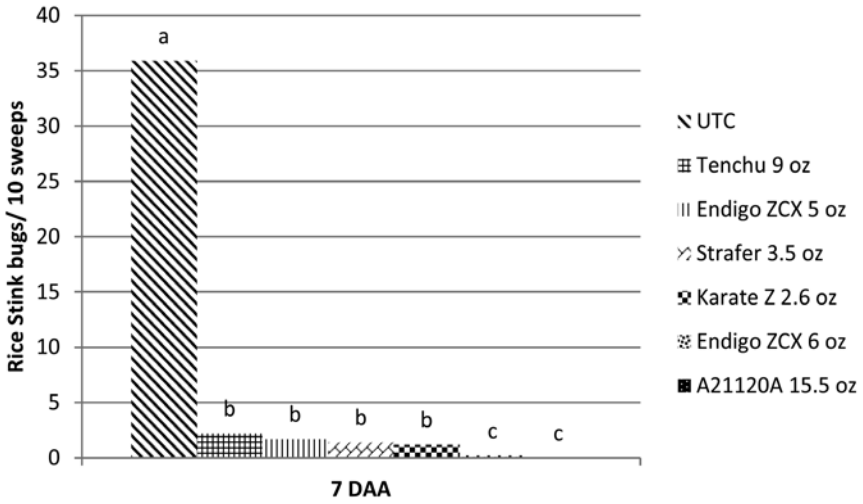

Fig. 2. Rice stink bug counts taken 28 August, 7 days after application (DAA). UTC = untreated check. Means followed by same letter do not significantly differ (*P* = 0.10, Duncan's New Multiple Range Test). Mean comparisons performed only when analysis of variance Treatment P (F) is significant at mean comparison observed significance level.

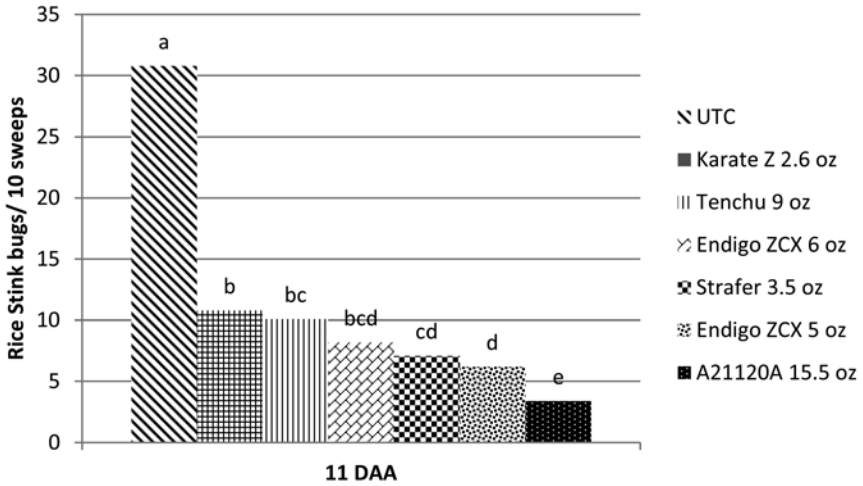

Fig. 3. Rice stink bug counts taken 1 September, 11 days after application (DAA). UTC = untreated check. Means followed by same letter do not significantly differ (P =0.10, Duncan's New Multiple Range Test). Mean comparisons performed only when analysis of variance Treatment P (F) is significant at mean comparison observed significance level.

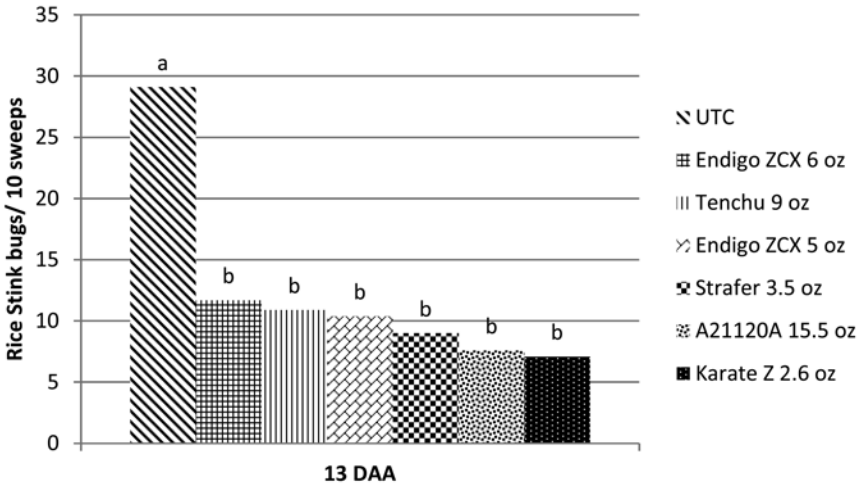

Fig. 4. Rice stink bug counts taken 3 September, 13 days after application (DAA). UTC = untreated check. Means followed by same letter do not significantly differ (*P* = 0.10, Duncan's New Multiple Range Test). Mean comparisons performed only when analysis of variance Treatment P (F) is significant at mean comparison observed significance level.

Evaluation of Rice Kernel Damage and Yields Due to Rice Stink Bug, *Oebalus pugnax*, Population and Infestation Timing

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ABSTRACT

The rice stink bug, *Oebalus pugnax*, is an important pest to rice that can reduce rough rice and milling yields. Field cage studies were conducted in 2015 at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center near Stuttgart, Ark., to evaluate the effect of different populations of rice stink bugs and infestation timings on kernel damage and grain yields. Our study did not show a reduction in rough rice yield or milling yields in any population or infestation timing. In the milk infestation timing, there was an increase in damaged kernels due to higher rice stink bug population densities.

INTRODUCTION

The rice stink bug, *Oebalus pugnax*, feeds on rice, *Oryza sativa* L., from heading to hard dough in the southern United States (Swanson and Newsom, 1962; Way and Bowling, 1991). During early stages of kernel development, the piercing-sucking stylet of the rice stink bug penetrates the rice hull and removes the content of the kernels 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). The rice inspection handbook allows for no more than 0.5% damaged grain in a 500 g sample to be considered U.S. grade 1 (USDA-FGIS, 2009). The stylets of rice stink bugs can carry fungi that cause this discoloration, or the fungi can enter through the wound at the feeding site after the rice stink bug has fed (Hollay et al., 1987). Farmers are penalized when pecky rice causes breakage during the milling process resulting in lower head rice yields (Way, 2003). This feeding can also result in reduced seed viability (Swanson and Newsom, 1962; Patel et al., 2006).

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Rice stink bugs usually move to rice from weeds or other rotational commodities during heading (Way, 2003). 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 and Hardke, 2013). Tindall et al. (2005) observed an increase in pecky rice with the presence of these weeds and an increase in unfilled kernels in the plots with rice stink bug presence.

The rice stink bug is managed with foliar insecticide sprays (Way, 2003). The economic threshold for stink bugs in Arkansas, during the first 2 weeks of heading, is 5 rice stink bugs in 10 sweeps with a sweep net, resulting in a recommended insecticide application. During the next 2 weeks at soft dough, the threshold is 10 rice stink bugs in 10 sweeps (Lorenz and Hardke, 2013). Some neighboring states have recently lowered their thresholds to 2 to 3 rice stink bugs per 10 sweeps until rice kernels have reached the hard dough stage.

Espino et al. (2007) showed the most susceptible stages of panicle development to the rice stink bug feeding were milk and soft dough. The least desirable rice plants were those in the preheading stage (Espino and Way, 2008). Bowling (1963) showed that populations of rice stink bugs during the early stages of flowering increased the number of non-filled seed, while others did not show any yield loss (Blackman, 2014). Espino et al. (2007) found no differences in the amount and weight of complete kernels of rice infested during heading. Awuni et al. (2015) found the highest decrease in yield in the bloom stage and that milk and soft dough stages had the highest amount of atrophied kernels.

It is important to understand the damage at different rice growth stages caused by rice stink bug and the feeding densities that cause appreciable levels of damage to better help growers effectively and economically control this pest. The objective of our study was to determine the amount of yield loss and milling yield loss caused by different rice stink bug densities at different kernel development stages.

PROCEDURES

Experiments were conducted at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center near Stuttgart. The cultivar in these studies was Roy J, which was drill-seeded in early May 2015 and grown according to standard agronomic practices for Arkansas. Plots were 70 × 63 inches on 7-inch drill spacing. Cages were placed prior to heading to prevent natural infestations of rice stink bugs. Infestations of stink bugs were initiated once > 50% of panicles had reached the desired kernel development stage of flowering, milk, soft dough, or hard dough. Infested stink bugs were allowed to remain for 7 days, after which time infestations were terminated with foliar insecticide sprays and cages replaced with the plots remaining covered until harvest. Infestations levels were 0, 4, 8, 25, and 42 rice stink bugs per plot. The density of rice stink bugs/ft^2 is 0, 0.1307, 0.2614, 0.8170, and 1.3725. The experimental design was a randomized complete block with three replications per infestation timing.

Rice stink bug adults and late instar nymphs were collected with sweep nets in heading rice fields and weedy areas surrounding rice fields. Insects were kept in small

cages with fresh plant material and a moist paper towel in a laboratory at 75 °F for 48 h prior to infestation in field cages. Infestations in field cages were made early in the morning or late in the evening to help the rice stink bugs acclimate under less stressful environmental conditions to increase survival. Cage frames were 6 ft^3 made of 1-in. PVC pipe with 20 × 20 amber fabricated coverings (Lumite, Inc., Alto, Ga.) were used to cover each plot.

Prior to harvest, 10 rice panicles were removed and placed in a brown paper bag and stored in a dryer until moisture was 12%. The 10 panicles were harvested by hand and separated into seed and blanks; partial filled seeds were counted as seeds. Blanks and seeds were counted and the percentage of each plot was calculated. After the 10 panicles were removed, the center 5 rows of the plots were harvested with a plot combine and seed was stored in a cloth bag and placed in a dryer until the moisture was 12%. A random 100-g sample of seed harvested with the plot combine was dehulled. Using a light box, seed was separated into undamaged, rice stink bug damaged, kernel smut, false smut, and other damage. The seed in each category was weighed and the percentage of damage for each plot was calculated. After harvest, a random sample of 162 g of rough rice from each plot was used to evaluate grain milling quality. Rice was milled to obtain percent head rice (whole kernels) and percent total white rice (whole and broken kernels). 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 ($P = 0.10$).

RESULTS AND DISCUSSION

A significant difference was found between rice stink bug densities when infested at the rice milk development stage ($P < 0.10$, Table 1). Percent damaged kernels was significantly higher for plots infested with 0.26, 0.82, and 1.37 rice stink bugs/ft^2 compared to plots infested with 0 or 0.13 rice stink bugs/ft^2. No differences were observed between rice stink bug densities infested at the bloom, soft dough, hard dough stages ($P > 0.10$). In a greenhouse study, Espino et al. (2007) found differences between the amount of damaged rice in rice stink bug infestations made to rice at heading, milk, and soft dough. Comparing control plots to those infested with 15.79 rice stink bug/ft^2, soft dough had the highest percent of pecky rice, followed by milk, and then heading. Awuni et al. (2015) found a significant difference in damaged kernels between the non-infested plots and plots infested with 0.84 and 1.67 rice stink bug/ft^2 (Table 2).

No rice stink bug density resulted in significantly lower grain yield compared to the control (Table 3). Awuni et al. (2015) found uninfested plots yielded significantly higher than plots infested with 0.84 and 1.67 rice stink bug/ft^2 in their large cage study. Bowling (1963) only found a significant difference between the non-infested cage and the highest infested cage of 4 rice stink bug/ft^2.

There were no significant differences in the amount of unfilled kernels at different rice stink bug densities or infestation timings (Table 4). These results are similar to Blackman (2014), he found no significant differences in unfilled kernels with rice stink

bug densities ranging from 0.15 to 3.0 rice stink bug/ft^2. However, Espino et al. (2007), in a greenhouse study, saw a significant increase in unfilled kernels for rice infested at the heading stage compared to the uninfested control and rice infested at soft dough.

No decrease in total milled rice yield or head rice yield was observed for any rice stink bug density or infestation timing (Tables 5 and 6). These results are similar to Espino et al. (2007), who found no decrease in head rice milling yield for three of their experiments, including two greenhouse cage experiments and one field cage study. However, Bowling (1963) found varying decreases in milling yield associated with rice stink bug infestation densities of 1.0, 2.0, and 4.0 rice stink bugs/ft^2.

No decrease in rough rice yield resulted from increasing infestation densities of rice stink bugs during the selected stages of kernel development. Total percent damage only showed a significant difference when rice was infested during the milk stage at rice stink bug densities that greatly exceed current action thresholds for Arkansas. A wide range of injury to rice stink bug infestation has been found among current and previous research studies. This has resulted in different thresholds established by neighboring states throughout the mid-South and indicates the need for further study to more accurately determine the effect of rice stink bug on grain yield loss and grain quality.

SIGNIFICANCE OF FINDINGS

The rice stink bug is an important economic pest of rice. It is imperative that the University of Arkansas System Division of Agriculture Cooperative Extension Service provides growers with a threshold for control of this pest to avoid damage and/or quality losses, but equally important to avoid making unnecessary applications for control to maximize profit for rice growers.

ACKNOWLEDGMENTS

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Table 1. Percent damaged kernels based on weight in a 100-g brown rice sample for each rice growth stage and rice stink bug infestation density.

	Damaged kernels			
Infestation density	**Bloom**	**Milk**	**Soft dough**	**Hard dough**
(ft^2)	----------	(%)	----------	
0	1.20	0.91 b†	1.64	1.97
0.13	1.20	1.07 b	1.63	1.49
0.26	1.03	1.42 a	1.45	1.61
0.82	1.10	1.49 a	1.57	1.82
1.37	1.12	1.33 a	1.80	1.78
$LSD_{0.10}$	NS	0.2574	NS	NS
CV	22.4831	13.6280	12.4328	18.8347

† Means followed by the same letter within a column are not significantly different ($P < 0.10$).

Table 2. Calculated rice stink bug densities of previous caging studies.

Author	Type of study	Caged area	Caged area	Rice stink bug infested per cage	Calculated rice stink bug density
			(ft^2)		(ft^2)
Swanson and Newsom, 1962	Field cage	6 ft × 12 ft	66	0	0
				20	0.3030
				100	1.5152
				500	7.5758
			33	0	0
				20	0.6061
				100	3.0301
				500	15.1515
Bowling, 1963	Field cage	4 ft × 20 ft	80	0	0
				1	1
				2	2
				4	4
				Natural	Natural
		3 ft × 20 ft	60	0	0
				1	1
				2	2
				4	4
				Natural	Natural
Espino et al., 2007	Greenhouse cage	4 15-cm diam. pots	0.76	12/cage	15.789
Espino and Way, 2008	Greenhouse cage	4 15-cm diam. pots	0.76	10/cage	13.16
Blackman, 2014	Field cage	0.62 m^2	6.67	0/cage	0
				1/cage	0.1499
				2/cage	0.2999
				5/cage	0.7496
				10/cage	1.4993
				20/cage	2.9985
Awuni et al., 2015	Field cage	3.24 m^2	34.875	0/m^2	0
				9/m^2	0.8361
				18/m^2	1.6723
Lorenz and Hardke	Field cage		30.6	0	0
				4	0.1307
				8	0.2614
				25	0.8170
				42	1.3725

Table 3. Grain yield for each rice growth stage and rice stink bug infestation density.

	Grain yield			
Infestation density	Bloom	Milk	Soft dough	Hard dough
(ft^2)	(bu/acre)			
0	176.0	193.1	169.1	146.8
0.13	182.9	194.4	159.2	147.6
0.26	175.8	185.2	168.5	158.0
0.82	184.2	199.2	174.7	153.4
1.37	181.7	188.4	179.3	151.3
$LSD_{0.10}$	NS	NS	NS	NS
CV	4.0839	5.0108	6.4683	7.1455

Table 4. Percent blank kernels (based on kernel count) attributed to rice stink bug feeding in a 10 panicle rough rice sample for each rice growth stage and rice stink bug infestation density.

	Blank kernels			
Infestation density	Bloom	Milk	Soft dough	Hard dough
(ft^2)	(%)			
0	11.7	14.1	14.1	20.0
0.13	11.7	11.9	18.3	29.6
0.26	12.3	12.6	20.1	25.4
0.82	13.8	11.9	17.1	26.9
1.37	10.4	12.4	13.8	20.5
$LSD_{0.10}$	NS	NS	NS	NS
CV	17.9375	19.6384	25.7167	21.1187

Table 5. Percent milled total white rice yield in a 162-g sample for each rice growth stage and rice stink bug infestation density.

	Milled total white rice yield			
Infestation density	Bloom	Milk	Soft dough	Hard dough
(ft^2)	(%)			
0	74.34	74.26	73.50	73.29
0.13	74.26	74.34	73.31	73.19
0.26	74.34	74.36	73.62	73.37
0.82	73.83	73.97	73.91	72.72
1.37	74.20	74.22	73.64	72.74
$LSD_{0.10}$	NS	NS	NS	NS
CV	0.3876	0.4071	0.5530	0.5587

Table 6. Percent milled head rice yield in a 162-g sample for each rice growth stage and rice stink bug infestation density.

	Milled head rice yield			
Infestation density	**Bloom**	**Milk**	**Soft dough**	**Hard dough**
(ft^2)	----------	----------	(%)	----------
0	68.40 a†	66.98	67.26	66.93
0.13	67.78 b	67.39	66.83	67.04
0.26	68.64 a	66.28	66.93	67.43
0.82	67.84 b	66.42	67.06	66.46
1.37	68.27 a	66.36	67.67	66.60
$LSD_{0.10}$	0.4042	NS	NS	NS
CV	0.3654	0.9422	0.9448	0.7761

† Means followed by the same letter within a column are not significantly different ($P < 0.10$).

Potential Exposure of Honey Bees to Neonicotinoid Insecticides in Rice

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ABSTRACT

Insecticide seed treatments and foliar clothianidin applications were evaluated for expression in the flag leaf and floral parts of rice. Data analysis of samples indicate that neonicotinoid insecticides used as seed treatments or applied as early-season foliar treatments were expressed at very low levels or were nonexistent when samples were taken. Also, observations of bees visiting rice indicated extremely low levels of honey bees in rice fields.

INTRODUCTION

Recently, neonicotinoid insecticides used in agronomic crops have been scrutinized for their perceived impact on honey bee population decline in the U.S. In Arkansas, insecticides are essential to limit yield losses from insects in rice. Most notably, the neonicotinoid seed treatments CruiserMaxx Rice® and NipsIt™ INSIDE are important for rice water weevil and grape colaspis control. To date, all of the research focusing on the fate of neonicotinoid insecticides has been done in other southern crops such as corn, soybean, and cotton (Stewart et al., 2014)., No research has been conducted in rice to this point. As environmental groups continue to challenge the use of neonicotinoids in agriculture and pressure the U.S. Environmental Protection Agency to ban their use, it will become more important to generate information to refute their claims.

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PROCEDURES

Objective 1. Measuring Levels of Neonicotinoid Insecticides in Rice Plants at Flowering

Experiments were conducted at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center near Stuttgart Ark. The cultivar in these studies was CL151, which was drill-seeded on 6 May 2015 and grown according to standard agronomic practices for Arkansas. Plots were 9 rows on 7-inch drill spacing and 15 ft in length arranged in a randomized complete block design with four replications. The treatments included: an untreated check, Cruiser Maxx Rice 7 oz/cwt seed treatment; preflood Belay® 4.5 oz/acre; postflood Belay 4.5 oz/acre; and NipsIt INSIDE 1.92 oz/cwt seed treatment. CruiserMaxx Rice contains the neonicotinoid insecticide thiamethoxam while NipsIt INSIDE and Belay contain the neonicotinoid insecticide clothianidin. The Belay preflood application was made on 10 June and the postflood application was made 18 June. Flag leaf and panicle samples were taken 5 August, 60 days after planting, 25 days after preflood foliar application, and 17 days after postflood foliar treatment. Standard laboratory practices were conducted to ensure no contamination of samples occurred. Flag leaves from each plot were removed at the collar, placed in a labeled plastic bag, weighed, and stored on ice in a cooler. A sample size of 125 leaves was taken from the center rows of each plot to ensure enough tissue for testing. Each treatment was processed separately to lessen the possibility of contamination. Between each treatment, hands were cleaned with a 5% bleach solution, rinsed with water, and new gloves were used. The leaf tissue remained in a freezer until shipped. Panicles from each plot were removed, placed in a paper bag, stored on ice in a cooler, and brought to the laboratory for processing. A sample size of 50 panicles was removed to ensure enough tissue for testing. From each of 30 panicles, 15 florets were removed, placed in a labeled conical tube, and weighed to ensure 3 g of tissue were present. If the sample weighed less than 3 g, more florets were removed from the remaining panicles and the sample was weighed again. The tubes were placed in a freezer until shipped. To prepare for processing; tables, scales, and forceps were cleaned with a 5% bleach solution and wax paper was placed on each table to prevent contamination. Between each sample, the wax paper was removed, tables, forceps, and scales were cleaned with the bleach solution, and the tables were covered with a new piece of wax paper.

Samples were analyzed to determine the levels of neonicotinoid residues by the USDA AMS Science and Technology Laboratory Approval and Testing Division of the National Science Laboratories' Gastonia Lab in Gastonia, N.C. This laboratory is accredited to ISO/IEC 17025:2005 for specific tests in the fields of chemistry and microbiology, including testing for pesticide residues. The samples were extracted for analysis of agrochemicals using a refined methodology for the determination of neonicotinoid pesticides and their metabolites using an approach of the official pesticide extraction method (AOAC, 2007), also known as the QuEChERS method, and analyzed by liquid chromatography coupled with tandem mass spectrometry detection (LC/MS/MS). Samples were analyzed for the presence of 17 insecticides or their metabolites.

Quantification was performed using external calibration standards prepared from certified standard reference material. Only detections of clothianidin, imidacloprid, and thiamethoxam were reported. The method detection limit for these compounds was 1 ng/g (1 ppb).

Objective 2. Survey Conducted to Determine the Frequency at Which Honey Bees Visit Flowering Rice Plants

Beginning in late September, ten flowering rice fields in Arkansas and Jefferson counties were monitored for the presence of honey bees. Between the hours of 8:30 AM and 11:00 AM, at least five transects of 300-ft sections were observed by slowly walking and visually looking for honey bees visiting rice panicles. All observations were recorded as well as the location, stage of rice, and crops surrounding each field.

Data was processed using the latest version of Agriculture Research Manager (Gylling Data Management, Inc., Brookings, S.D.), analysis of variance, and Duncan's New Multiple Range Test ($P = 0.05$).

RESULTS AND DISCUSSION

Objective 1. Measuring Levels of Neonicotinoid Insecticides in Rice Plants at Flowering

In flag leaf samples taken at flowering, only the CruiserMaxx (thiamethoxam) IST indicated a low level of detection at 7.93 ppb; NipsIt INSIDE and both Belay foliar applications had no detection of clothianidin as seen in the untreated check (Table 1.) A similar trend was observed for pollen with an even lower level of CruiserMaxx found in florets and pollen with 2.23 ppb and all other treatments having no detection of clothianidin. This study correlates well with a previous study (Stewart et al., 2014) on cotton, soybean, and corn where very low levels of detections were found in pollen.

Objective 2. Survey Conducted to Determine the Frequency at Which Honey Bees Visit Flowering Rice Plants

A total of 57 transects were made. In those transects, only one bee was observed (Tables 2 and 3). There was no difference in bee population between time, day, or stage of rice. The crops surrounding each field had no impact on the appearance of bees in rice fields. Rice, like most of our major row crops, is predominantly self-pollinated and from these studies does not appear to be attractive to bees.

SIGNIFICANCE OF FINDINGS

In previous studies we have demonstrated that insecticide seed treatments not only provide protection of the rice plant from insects and reduce stress, but increase

yields and profitability and are vital for rice production in Arkansas and the mid-South. Although neonicotinoid insecticide seed treatments have been under fire recently for impact on honey bees, these and other studies continue to show it is largely unfounded and focus should be placed on the real issues impacting pollinators.

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We would like to express our appreciation for funding and support for these studies from the Arkansas rice producers through monies administered by the Rice Research and Promotion Board and the University of Arkansas System Division of Agriculture.

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Table 1. Levels of neonicotinoid insecticides (ppb) in the flag leaf and florets of rice from plots treated with thiamethoxam and clothianidin insecticide seed treatments at planting and clothianidin foliar applications made preflood or postflood on rice at bloom (60 days after planting, 25 days after preflood application, and 17 days after postflood application).

Treatment	Rate/acre	Active ingredient	Flag leaf†	Pollen†
			----------(ppb)	----------
Untreated check		NA	0.0 b	0.0 b
CruiserMaxx rice	7 oz/ cwt	thiamethoxam	7.93 a	2.23 a
NipsIt INSIDE	1.92 oz/ cwt	clothianidin	0.0 b	0.0 b
Belay preflood	4.5 oz/ acre	clothianidin	0.0 b	0.0 b
Belay postflood	4.5 oz/ acre	clothianidin	0.0 b	0.0 b

† Means followed by the same letter do not significantly differ at least significant difference $P = 0.05$.

Table 2. Observations of the number of bees observed in flowering rice fields at different times of the day at 300 ft transects across the field in Jefferson and Arkansas Counties (Observations = 57).

				Number of bees in transect					
Field	**Growth stage**	**Date**	**Time**	**1**	**2**	**3**	**4**	**5**	**6**
1	Flowering	9/21	8:30 AM	0	0	0	0	0	0
2	Flowering	9/24	9:15 AM	0	0	0	0	0	0
3	Flowering	9/24	10:00 AM	0	0	1	0	0	0
4	Flowering and milk	9/24	10:50 AM	0	0	0	0	0	0
5	Flowering and milk	9/25	9:10 AM	0	0	0	0	0	-
6	Flowering	9/25	9:35 AM	0	0	0	0	0	-
7	Flowering	9/25	10:00 AM	0	0	0	0	0	-
8	Flowering and milk	9/28	9:20 AM	0	0	0	0	0	0
9	Flowering	9/28	10:00 AM	0	0	0	0	0	0
10	Flowering	10/1	10:00 AM	0	0	0	0	0	0

Table 3. Field location of bee observations and surrounding crops or vegetation.

Field	Field location	North of field	South of field	East of field	West of field
1	Arkansas	Soybeans	Mature rice	Mature rice	Soybeans
2	Jefferson	Mature rice	Soybeans	Mature rice	Soybeans
3	Jefferson	Tree line	Soybeans	Tree line	Soybeans
4	Arkansas	Soybeans	Soybeans	Tree line	Mature rice
5	Jefferson	Flowering rice	Tree line	Soybeans	Mature rice
6	Jefferson	Fallow	Flowering rice	Soybeans	Mature rice
7	Jefferson	Mature corn	Tree line	Mature corn	Cut milo
8	Arkansas	Soybeans	Soybeans and mature corn	Soybeans	Mature rice
9	Arkansas	Soybeans	Soybeans	Flowering rice	Soybeans
10	Arkansas	Tree line	Soybeans	Tree line	Flowering rice

Value of Insecticide Seed Treatments in Arkansas Rice

N.M. Taillon[1], G.M. Lorenz[1], W.A.Plummer[1], H.M. Chaney[2], and J. Black[1]

ABSTRACT

Rice insecticide seed treatment (IST) trials from 2008 through 2015 were analyzed to determine impact on plant stand and yield to determine economic benefit to producers. Data was summarized across all trials and results indicated a significant increase in both stand and yield.

INTRODUCTION

Rice water weevil and grape colaspis are common pests in Arkansas rice that have the potential to reduce stand counts and yield. In 2010, Cruiser® (Syngenta Crop Protection) and Dermacor® X-100 (DuPont Crop Protection) received full labels and in 2012 NipsIt® INSIDE (Valent U.S.A. Co.) received a full label permit for use in rice to provide effective control of both insects during the developmental stages of rice. Throughout testing there was a general trend for seed treatments to improve stand count and yield (Lorenz et al., 2013). We observed many times that under stressful conditions, the seed treatment helped to moderate or buffer stress (Taillon et al., 2014).

PROCEDURES

Trials were conducted on numerous grower fields across the state, at the University of Arkansas System Division of Agriculture's Pine Tree Research Station near Colt, Ark., and at the Rice Research and Extension Center near Stuttgart, Ark. The selection of locations was based on fields with a history of problems with either grape colaspis or rice water weevil. However, we did not experience insect problems in every field. These trials consisted of a small plot randomized complete block design with 4 replications as well as large plot demonstration trials in a randomized strip block design with a minimum of 3 replications. Seed treatments included Cruiser 5FS 3 oz/cwt (thiamethoxam) or CruiserMaxx Rice (thiamethoxam + fungicides premix), Dermacor X-100 1.5-6 oz/cwt (chorantraniliprole), and NipsIt INSIDE 1.92 oz/cwt (clothianidin). All seed treatments,

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as well as the check, included a fungicide package of Apron XL (Mefenoxam), Maxim 4 FS (Fludioxonil), and Dynasty 83 FS (Azoxystrobin). Seed treatments were applied at the University of Arkansas System Division of Agriculture's Lonoke Extension Center, Lonoke, Ark. using small and large batch seed treaters. Tests were conducted with these seed treatments on conventional, Clearfield, and hybrid cultivars of rice using standard seeding rates. Stand count data was collected 2 to 3 weeks post planting by counting plants in 10 row feet per plot. Yields for small plot trials were taken with a plot combine and large block tests were harvested with a standard combine. A metadata analysis across these trials was conducted to determine the effect of insecticide seed treatments on stand establishment and yield. Data was processed using the latest version of Agriculture Research Manager (Gylling Data Management, Inc., Brookings, S.D.), analysis of variance, and Duncan's New Multiple Range Test ($P = 0.10$).

RESULTS AND DISCUSSION

Results indicated that seed treatments increased stand counts in many trials 0% to 58% above the untreated check (UTC) and averaged 14.5% across 201 trials (Fig. 1). Cruiser-treated plots had an increase in stand counts ranging from 0% to 58% above the UTC with an average stand increase of 15.8% across 87 trials (Fig. 2). NipsIt seed treatment had an increase in stand counts ranging from 1.6% to 53% above the UTC, and averaged 15.1% across 51 trials (Fig. 3). Dermacor-treated plots had an increase in stand counts ranging from 0.3% to 39.8% above the UTC with an average increase of 12% across 61 trials (Fig. 4).

Seed treatments across 201 trials provided an average 8.33 bu/acre increase compared to the untreated check (Fig. 5). Based on the yield results shown in the figures below, Cruiser, NipsIt, and Dermacor provided a 76%, 75%, and 85% probability of a net return, respectively (Figs. 6, 7, and 8).

SIGNIFICANCE OF FINDINGS

Insecticide seed treatments not only improve stand counts, but also increase yields 80% of the time for Arkansas rice producers. This allows growers the flexibility of choosing lower seeding rates to reduce input costs while still maintaining profitability. Based on our findings, these seed treatments are recommended for use in Arkansas rice. Research will continue to evaluate new chemistries.

ACKNOWLEDGMENTS

We would like to acknowledge funding for this project was provided by: Rice Check-Off funds, administered by the Rice Research and Promotion Board, University of Arkansas System Division of Agriculture, Syngenta, Valent, and Dupont. We also thank Jarrod Hardke and his crew at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center, and Shawn Clark and his crew at

the University of Arkansas System Division of Agriculture's Pine Tree Research Station for their cooperation and support in these studies.

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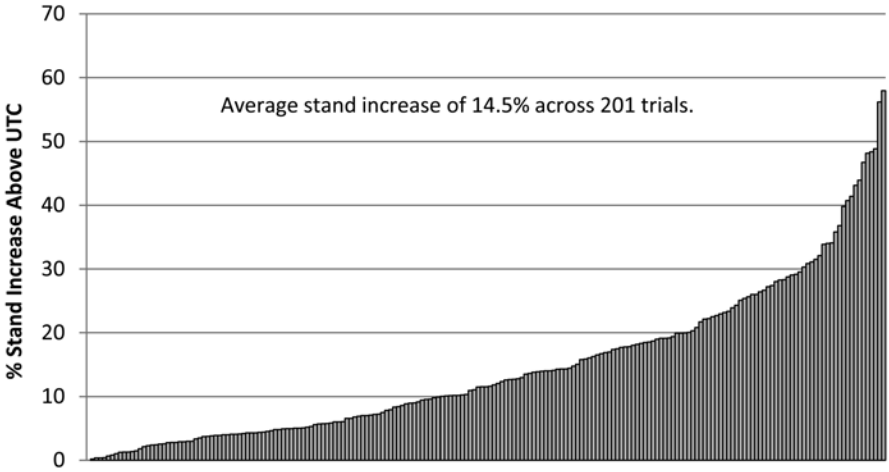

Fig. 1. Percent stand increase of insecticide seed treatments over untreated check (fungicide only) across 201 trials from 2008 to 2015.

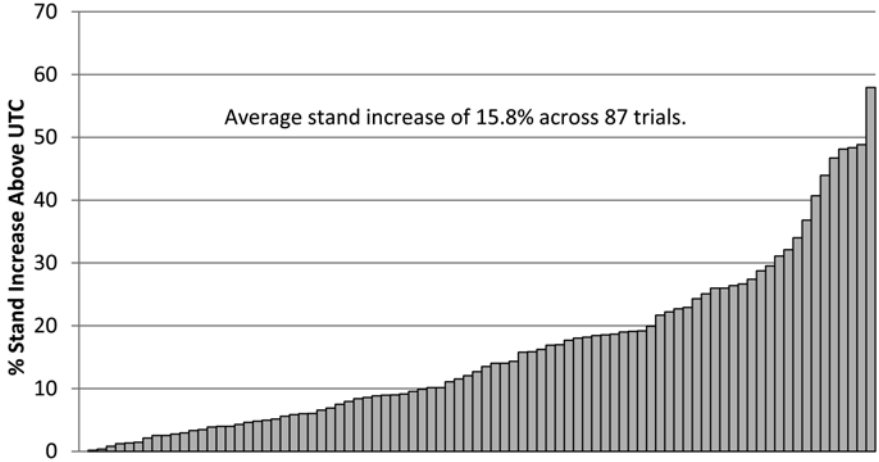

Fig. 2. Percent stand increase of Cruiser/CruiserMaxx® over untreated check (fungicide only) across 87 trials from 2008 to 2015.

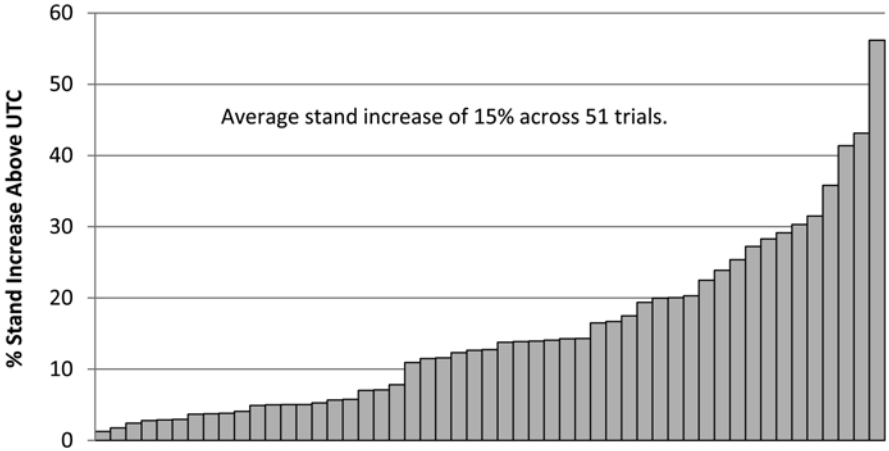

Fig. 3. Percent stand increase of NipsIt® INSIDE over untreated check (fungicide only) across 51 trials from 2008 to 2015.

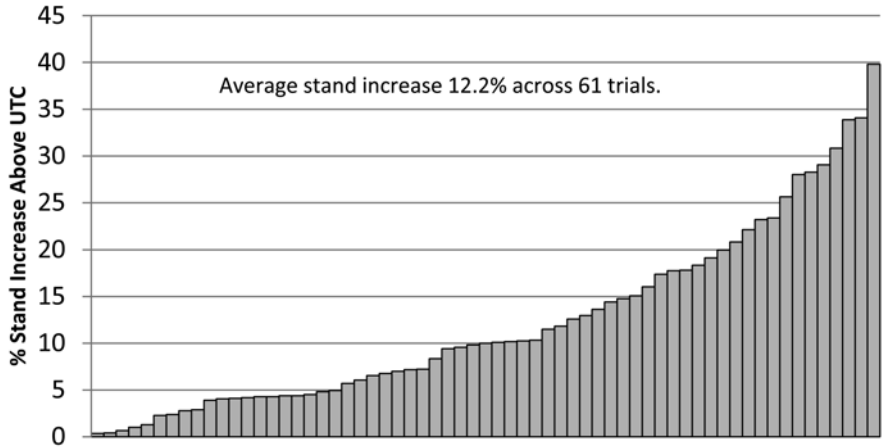

Fig. 4. Percent stand increase of Dermacor® over untreated check (fungicide only) across 61 trials from 2008 to 2015.

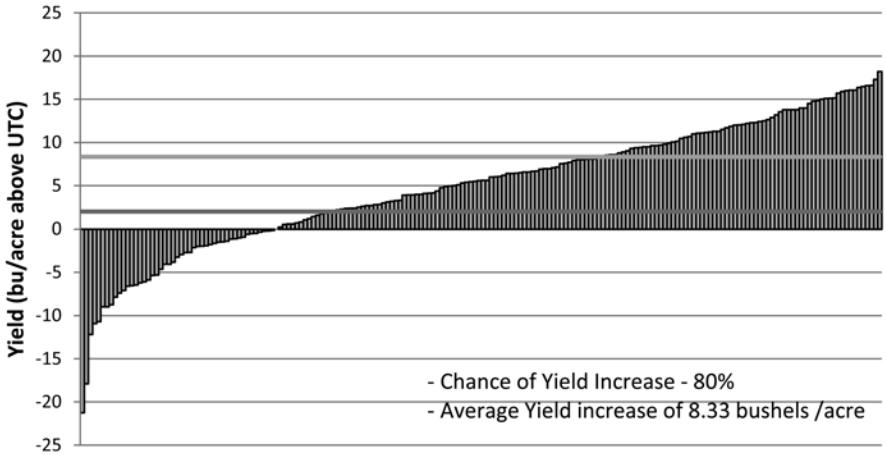

Fig. 5. Percent yield increase of insecticide seed treatments over untreated check (fungicide only) across 201 trials from 2008 to 2015.

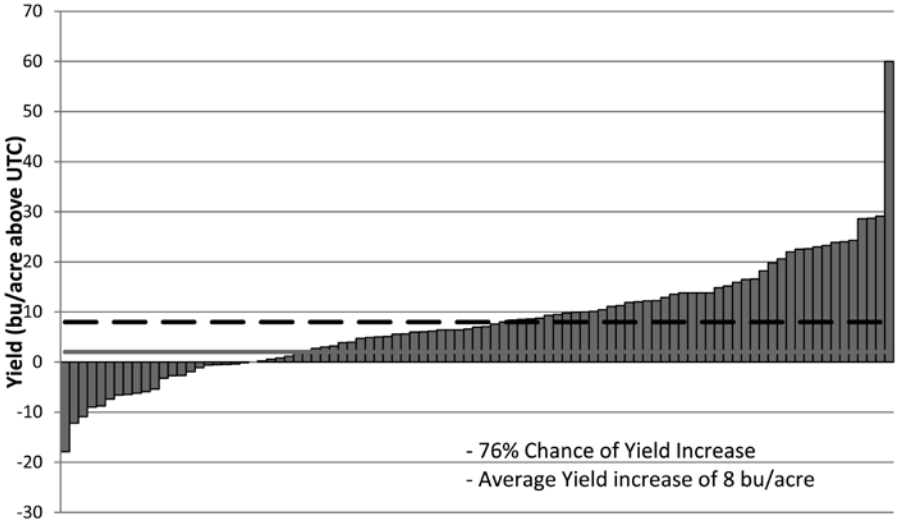

Fig. 6. Percent yield increase of Cruiser/CruiserMaxx® over untreated check (fungicide only) across 87 trials from 2008 to 2015.

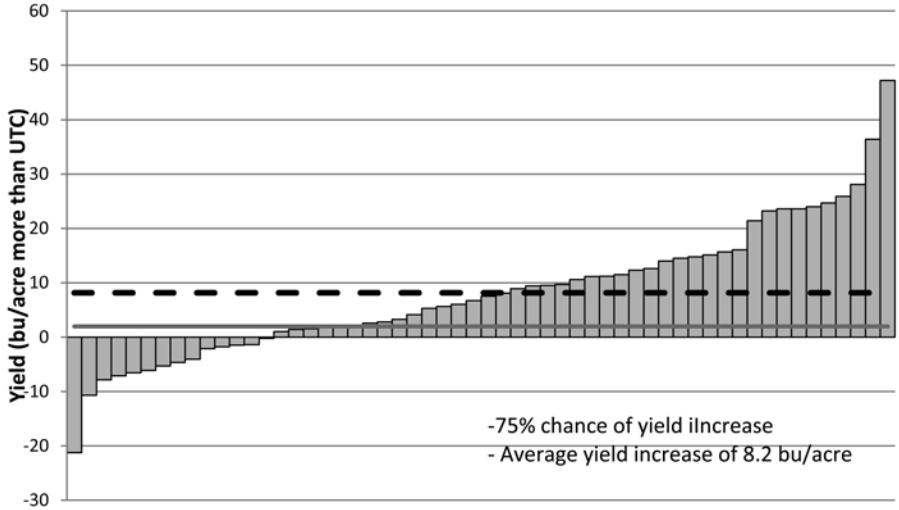

Fig. 7. Percent yield increase of NipsIt® INSIDE over untreated check (fungicide only) across 51 trials from 2008 to 2015.

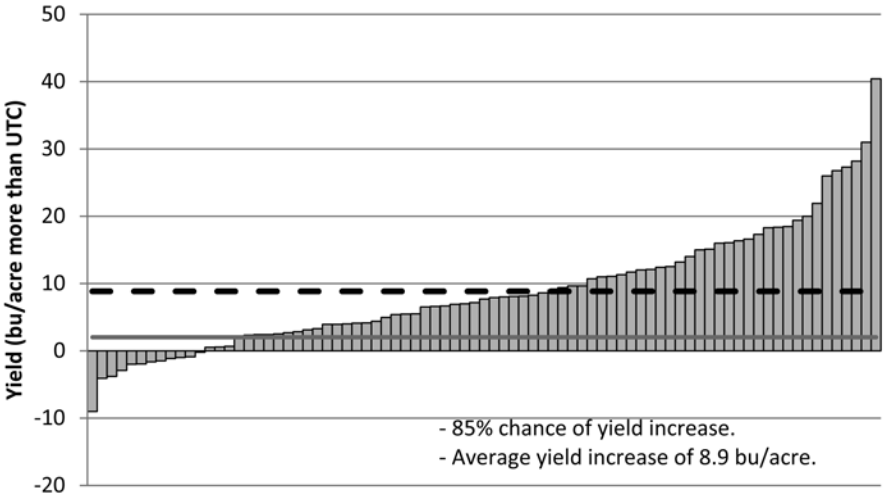

Fig. 8. Percent yield increase of Dermacor® over untreated check (fungicide only) across 61 trials from 2008 to 2015.

Residual Weed Control and Crop Response to Pethoxamid Systems in Rice

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

ABSTRACT

Rice weed control systems in Arkansas are complex and must contain multiple modes of action to provide control of troublesome weed species. Many weed control programs no longer provide adequate control of some of the most troublesome weeds such as barnyardgrass and Amazon sprangletop. A trial was conducted in 2015 to evaluate weed control and crop response to pethoxamid, a new potential residual herbicide in rice. Pethoxamid controlled barnyardgrass and Amazon sprangletop 80% to 91% alone and up to 96% and 98%, respectively, when tank-mixed with imazethapyr at 0.063 lb ai/acre and applied delayed-preemergence to spiking rice. Eclipta control was also improved with the addition of pethoxamid to clomazone at 0.3 lb ai/acre or imazethapyr at 0.063 lb ai/acre. No rice injury was caused by any pethoxamid-containing treatment. Pethoxamid does provide an additional mode of action which increases control of barnyardgrass, Amazon sprangletop, and eclipta in Arkansas rice.

INTRODUCTION

Clomazone, quinclorac, and pendimethalin are relied upon heavily to provide early-season residual grass control in Arkansas rice. The use of these herbicides is crucial for early season systems to be successful (Scott et al., 2015). Due to increased barnyardgrass resistance to multiple herbicide modes of action such as propanil, imazethapyr, and quinclorac when applied post-emergence, pre-emergence systems are becoming much more important to provide complete control of barnyardgrass prior to flooding rice. The prevention of herbicide resistance is also a driving force in the use of multiple modes of action in rice weed control. Pethoxamid, a new chloroacetamide herbicide and a new potential mode of action for grass control in rice, has proven beneficial when used in weed control programs in other crops. Jursik et al. (2013) found that pethoxamid provided good control of redroot pigweed and barnyardgrass when

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applied pre-emergence in sunflower. The purpose of this research was to evaluate the effectiveness of pethoxamid herbicide on grass control in rice, and to determine if any crop injury would occur.

PROCEDURES

A trial was conducted in 2015 at the University of Arkansas System Division of Agriculture's Southeast Research and Extension Center in Monticello, Ark., to evaluate weed control and crop response to pethoxamid herbicide systems in rice. A randomized complete block design with four replications was used. The cultivar CL111 was drill-seeded into Sharkey clay soil at 90 lb/acre, and weed seed were broadcast after planting rice. Pethoxamid was applied alone at 0.375 or 0.5 lb ai/acre and in conjunction with clomazone (0.3 lb ai/acre), imazethapyr (0.063 lb ai/acre), pendimethalin (1.0 lb ai/acre), and quinclorac (0.375 lb ai/acre). Treatments were applied using a Mudmaster sprayer equipped with a compressed air powered multi-boom, calibrated to deliver 12 gal/acre. Treatments were applied 6 days after planting to spiking rice. Weed control and crop injury were evaluated on a scale from 0% to 100%, where 0% equals no weed control or crop injury and 100% equals complete control. Data were subjected to analysis of variance and means were separated using Fisher's protected least significant difference test ($P = 0.05$).

RESULTS AND DISCUSSION

Pethoxamid at 0.375 or 0.5 lb ai/acre applied alone, or in combination with clomazone, imazethapyr, pendimethalin, or quinclorac, provided equivalent control (97% to 99%) of barnyardgrass, Amazon sprangletop, and eclipta 26 days after application (DAA). No crop injury was caused by any treatment, pethoxamid alone or in combination with any other herbicide used, 26 DAA (data not shown).

Sixty six DAA pethoxamid at 0.375 and 0.5 lb ai/acre provided 84% and 80% control of barnyardgrass, respectively, which was similar to all other standard herbicides including clomazone and pendimethalin (Table 1). However, when pethoxamid at 0.375 and 0.5 lb ai/acre was mixed with imazethapyr at 0.063 lb ai/acre, barnyardgrass control increased to 93% and 96%, respectively. All other pethoxamid combination treatments provided 90% or less barnyardgrass control. Pethoxamid at 0.375 lb ai/acre provided 91% control of Amazon sprangletop at 66 DAA. The addition of other herbicides such as pendimethalin at 1.0 lb ai/acre, imazethapyr at 0.063 lb ai/acre, or the higher rate of pethoxamid (0.50 lb ai/acre) did not improve control over pethoxamid alone at the 0.375 lb ai/acre rate. Control of Amazon sprangletop was the highest (98%) 66 DAA with the combination of pethoxamid at 0.5 lb ai/acre plus imazethapyr at 0.063 lb ai/acre. All other treatments provided 94% or less control of Amazon sprangletop. Pethoxamid at 0.375 lb ai/acre controlled eclipta 97% at 66 DAA and was not significantly different than all other herbicides tested alone or in combination which controlled eclipta 95% to 99%. Pethoxamid at 0.5 lb ai/acre provided 94% control of eclipta 66 DAA and was

significantly lower than five treatments that provided 99% control. No crop injury was observed 66 DAA by any treatment, pethoxamid alone or in combination with any other herbicide used in this trial.

SIGNIFICANCE OF FINDINGS

Pethoxamid herbicide provided excellent control of both barnyardgrass and Amazon sprangletop and appears to have potential to be a reliable rice herbicide for long lasting residual grass control. The best overall treatment was pethoxamid at 0.5 lb ai/acre plus Imazethapyr at 0.063 lb ai/acre, which provided 96%, 98%, and 99% control of barnyardgrass, sprangletop, and eclipta, respectively. No significant crop injury was caused by any treatment, which further supports the use of pethoxamid at the delay-preemergence or spiking stage in Arkansas rice weed control programs. If labeled, pethoxamid can provide an alternative mode of action for improved grass weed control in rice.

ACKNOWLEDGMENTS

Special appreciation is extended to the Arkansas Rice Research and Promotion Board and the University of Arkansas System Division of Agriculture for providing funding for this project.

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Table 1. Weed control and crop response to pethoxamid 66 days after application.

Treatment	Rate	Timing	Weed control: Barnyard-grass	Weed control: Amazon sprangletop	Weed control: Eclipta	Crop injury: Stunting
	(lb ai/acre)		----------(%)----------			
Pethoxamid	0.375	spike	84	91	97	0
Pethoxamid	0.5	spike	80	86	94	0
Clomazone	0.3	spike	76	44	95	0
Pethoxamid	0.375	spike	81	90	99	0
Clomazone	0.3					
Pethoxamid	0.5	spike	79	86	96	0
Clomazone	0.3					
Imazethapyr	0.063	spike	84	74	97	0
Pethoxamid	0.375	spike	93	91	98	0
Imazethapyr	0.063					
Pethoxamid	0.5	spike	96	98	99	0
Imazethapyr	0.063					
Pendimethalin	1.0	spike	91	80	97	0
Pethoxamid	0.375	spike	90	91	95	0
Pendimethalin	1.0					
Pethoxamid	0.5	spike	84	94	96	0
Pendimethalin	1.0					
Quinclorac	0.375	spike	86	45	99	0
Pethoxamid	0.375	spike	86	83	99	0
Quinclorac	0.375					
Pethoxamid	0.5	spike	84	89	99	0
Quinclorac	0.375					
$LSD_{0.05}$			11	12	4	NS[a]

[a] NS = not significant.

Evaluation of Very Long-Chain Fatty Acid-Inhibiting Herbicides in Arkansas Rice

J.A. Godwin Jr.[1], J.K. Norsworthy[1], R.C. Scott[2], L.T. Barber[2], M.L. Young[1], and M.W. Duren[3]

ABSTRACT

Two field experiments were conducted in 2015 to evaluate the use of very long-chain fatty acid-inhibiting (WSSA Group 15) herbicides in Arkansas rice on silt loam and silty clay soils. The experiments were designed as a three (application timings) by four (herbicides) factorial in a randomized complete block design. The herbicides included Warrant (acetochlor at 0.94 lb ai/acre), Zidua (proxasulfone at 0.133 lb ai/acre), Dual Magnum (S-metolachlor at 0.955 lb ai/acre), and pethoxamid at 0.75 lb ai/acre applied delayed pre-emergence (DPRE), spiking, and at the 1- to 2-lf rice stages. Of the herbicides evaluated, pyroxasulfone caused the most crop injury. On the silt loam soil, pyroxasulfone caused 68% rice injury, averaged over all application timings. Unacceptable levels of injury to rice also occurred with S-metolachlor, although, rice appeared more tolerant to S-metolachlor at the silty clay soil location. Averaged across application timings, rice exhibited acceptable tolerance to pethoxamid and acetochlor at both locations. Because of the tolerance of rice to acetochlor and pethoxamid observed in this work, additional research is merited to understand the level of weed control that can be obtained with these herbicides in Arkansas rice systems.

INTRODUCTION

Due to the repetitive use of the same herbicide mechanisms of action (MOA) in Arkansas rice, the evolution of resistance has occurred in several common weeds. Herbicide resistance in barnyardgrass (*Echinochloa crus-galli*) and red rice (*Oryza sativa*) has resulted in increased weed management difficulties for growers across the state. Many of the most commonly used herbicide MOA in rice have an extremely high risk for resistance: ALS inhibitors (157 resistant species worldwide), PSII inhibitors (73 resistant species worldwide), ACCase inhibitors (47 resistant species worldwide), and

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synthetic auxins (32 resistant species worldwide) (Heap, 2015). Hence, it is important to integrate new MOA into rice whenever possible in order to combat or prevent the further development of resistant weeds. Group 15 herbicides are commonly used in the U.S. in crops such as corn, soybean, and cotton for control of annual grasses and small-seeded broadleaves. Currently, there are no Group 15 herbicides used in U.S. rice production; however, Group 15 herbicides such as pretilachlor and butachlor are commonly used with great success in Asian dry-seeded rice culture (Chauhan, 2012). Group 15 herbicides are at a relatively low risk for resistance when compared to other MOA considering that there are only four resistant weed species worldwide (Heap, 2015). With success in other U.S. crops, Asian rice, and a low risk for resistance, Group 15 herbicides may have a potential fit in Arkansas rice. The objectives of this research were to evaluate four group 15 herbicides at three different application timings for potential use in rice based on crop tolerance.

PROCEDURES

Two field experiments were conducted in 2015 at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC) near Stuttgart, Ark., and the Northeast Research and Extension Center (NEREC) in Keiser, Ark., to evaluate the use of very long-chain fatty acid-inhibiting (WSSA Group 15) herbicides in Arkansas rice. These locations represent two distinct soil types, a DeWitt silt loam (RREC) and a Sharkey silty clay soil (NEREC). The experiments were designed as a three (application timings) by four (herbicides) factorial in a randomized complete block design. The herbicides: Warrant (acetochlor at 0.94 lb ai/acre), Zidua (pyroxasulfone at 0.133 lb ai/acre), Dual Magnum (S-metolachlor at 0.955 lb ai/acre), and pethoxamid at 0.75 lb ai/acre were applied delayed pre-emergence (DPRE), at spiking, and to 1- to 2-lf rice. A control (check) was included for comparison. All plots were maintained weed-free throughout the experiments using herbicides labeled for rice and applied as needed.

Clearfield™ 111 rice was planted at 22 seed/ft of row in 7.5-inch-wide rows in 6 × 20 ft plots. All herbicides were applied with a CO_2-pressurized backpack sprayer at 15 gallons of spray solution per acre. Observations were taken on rice injury on a scale of 0 to 100, with 0 being no injury and 100 being complete crop death. Rough rice grain was harvested at crop maturity using a small-plot combine. All data were subjected to analysis of variance and means were separated using Fisher's protected least significant difference test (0.05).

RESULTS AND DISCUSSION

Silt Loam Soil

There was no interaction between herbicide and application timing for injury rated 2 to 3 weeks after treatment (WAT); however, both main effects were significant. Averaged across application timings, rice exhibited the greatest tolerance to acetolachlor and pethoxamid, with injury averaging no more than 5% for both herbicides (Fig. 1). As ap-

plication timing was delayed, rice tended to have greater tolerance to all herbicides (data not shown). Due to the reactivation of herbicides after establishment of the permanent flood, rice injury increased substantially for pyroxasulfone and S-metolachlor to unacceptable levels (Fig. 2), but rice injury did not increase for acetochlor and pethoxamid.

Rough rice yield was statistically similar to the nontreated check for acetochlor treatments applied at spiking and to 1- to 2-lf rice and pethoxamid at all application timings (Table 1). Significant reduction in rice yields resulted for all pyroxasulfone and S-metolachlor application timings compared to the nontreated checkand when compared to most of the acetolachlor and pethoxamid timings.

Silty Clay Soil

There was only a herbicide main effect at 4 to 5 (Fig. 3) and at 7 to 8 WAT (data not shown) for rice injury. At both evaluation dates, pyroxasulfone caused the greatest amount of rice injury, whereas injury was minimal following S-metolachlor, pethoxamid, and acetochlor applications. Similar to the silt loam soil, rice injury on the silty clay soil increased after the permanent flood was established (data not shown).

Rough rice yields following acetochlor and pethoxamid DPRE and pethoxamid at spiking were comparable to the nontreated control (Table 1). Similar to the silt loam site, rice treated with pyroxasulfone often yielded the lowest among all treatments (Table 1).

SIGNIFICANCE OF FINDINGS

On both soils, rice exhibited a high level of tolerance to pethoxamid and acetochlor. Neither of these herbicides are currently labeled in rice, nor are there other products labeled in rice having a similar MOA. Hence, either of these products could potentially provide growers additional options in the battle against and to prevent the development of herbicide-resistant barnyardgrass, especially considering that acetochlor is currently labeled in other mid-South crops and has demonstrated a high level of barnyardgrass control in other research (Riar et al., 2011). In the upcoming year, efforts will continue around testing pethoxamid and acetochlor across soil textures and environments in rice along with evaluating weed control programs that contain these two herbicides.

ACKNOWLEDGMENTS

We thank the staff at both the RREC and NEREC for help with this research, and appreciate the Arkansas Rice Research and Promotion Board for funding this research as well as the University of Arkansas System Division of Agriculture.

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Table 1. Rough rice yields following applications of four Group 15 herbicides at three application timings on the DeWitt silt loam soil at the Rice Research and Extension Center, near Stuttgart, Ark., and the Sharkey silty clay soil at the Northeast Research and Extension Center, Keiser, Ark.

		Rough rice yield (bu/acre)	
Herbicide	**Timing†**	**Silt loam**	**Silty clay**
None (Check)	------	175 ab‡	147 a
Acetochlor	DPRE	157 cd	137 a-d
	Spiking	162 b-d	127 d
	1-to 2-lf rice	180 a	132 b-d
Pethoxamid	DPRE	161 b-d	140 a-c
	Spiking	162 a-d	14 ab
	1-to 2-lf rice	168 a-c	130 cd
S-metolachlor	DPRE	139 e	106 e
	Spiking	134 e	97 ef
	1-to 2-lf rice	147 de	140 a-c
Pyroxasulfone	DPRE	80 g	88 fg
	Spiking	100 f	83 g
	1- to 2-lf rice	91 fg	89 fg

† Abbreviations: delayed pre-emergence (DPRE) and leaf (lf).

‡ Means within a column followed by the same letter are not significantly different based on Fisher's protected least significant difference test ($P < 0.05$).

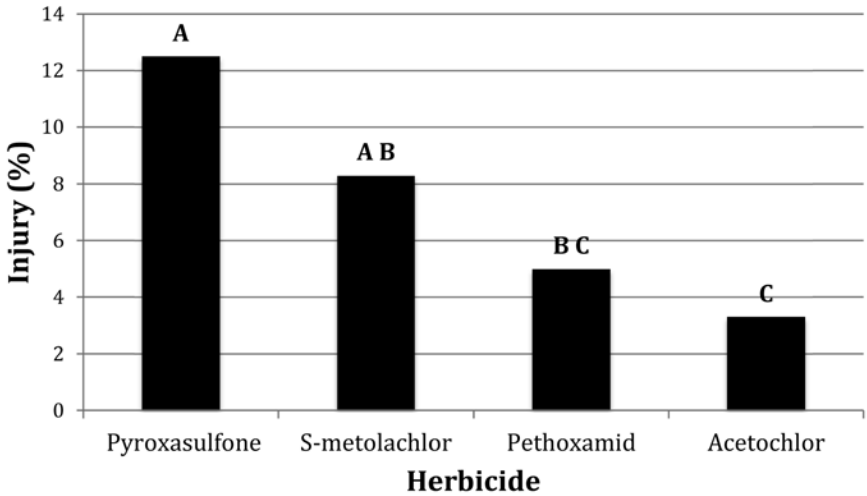

Fig. 1. Rice injury observed following application of four Group 15 herbicides 2 to 3 weeks after treatment at the Rice Research and Extension Center. Means followed by the same letter are not significantly different according to Fisher's protected least significant difference test at *P* = 0.05.

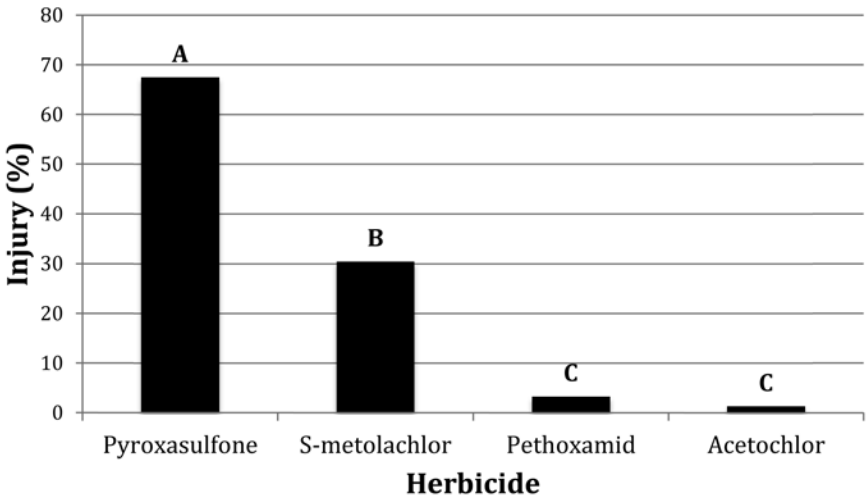

Fig. 2. Rice injury observed following application of four Group 15 herbicides 8 to 9 weeks after treatment at the Rice Research and Extension Center. Means followed by the same letter are not significantly different according to Fisher's protected least significant difference test at *P* = 0.05.

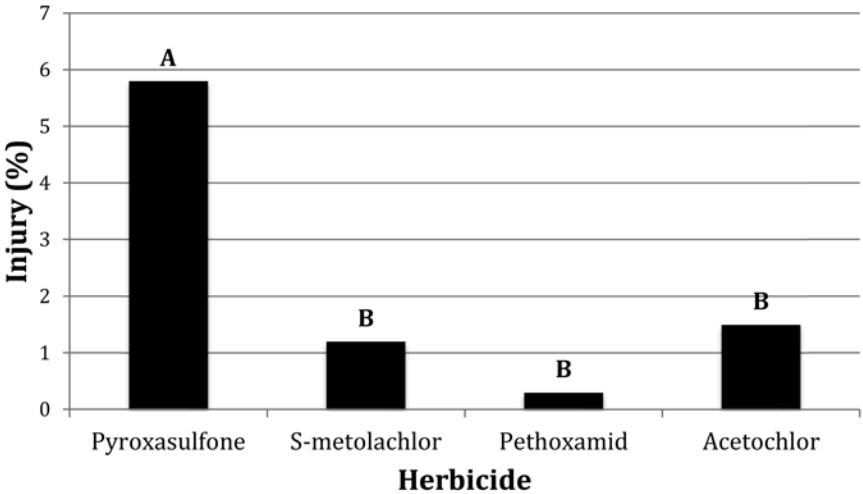

Fig. 3. Rice injury observed following application of four Group 15 herbicides 4 to 5 weeks after treatment at the Northeast Research and Extension Center. Means followed by the same letter are not significantly different according to Fisher's protected least significant difference test at *P* = 0.05.

Sharpen Tank-Mixtures with Rice Herbicides for Barnyardgrass Control in Provisia™ Rice

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ABSTRACT

Provisia™ rice is a new non-genetically modified organism (GMO) trait resistant to quizalofop, an acetyl-coenzyme A carboxylase (ACCase)-inhibiting herbicide (Group 1) that only controls grass weed species. Often in rice, both broadleaf and grass weeds are present in the field and a broadleaf herbicide is needed as a tank-mixture or as a split application when applying a selective grass herbicide. A field experiment was conducted in the summer of 2015 at the University of Arkansas System Division of Agriculture Pine Tree Research Station near Colt, Ark, to evaluate the possible interaction of Sharpen herbicide when applied in tank-mixtures with other rice herbicides typically used for controlling barnyardgrass (*Echinochloa crus-galli*). This experiment was set up as a randomized complete block design with three factors: herbicide, rate, and the addition of Sharpen. Herbicide treatments were 1/2× and 1× labeled rates of Sharpen (saflufenacil), Clincher (cyhalofop), Ricestar HT (fenoxaprop), and Provisia (quizalofop - soon to be labeled). Overall, injury did not exceed 5% for any treatment, regardless of herbicide, rate, or the addition of Sharpen at 7 and 14 days after treatment (DAT). Antagonism was seen at 7 DAT for 1/2× rates of Sharpen + Clincher; and by 14 DAT, the 1/2× rate of Sharpen + Clincher and the 1× rate of Sharpen + Ricestar HT were also deemed antagonistic. Based on these results, tank-mixing Sharpen with Clincher or Ricestar HT may result in a decrease in barnyardgrass control; hence, split applications may be considered when using these herbicides if broadleaf and grass weeds are both present in the field.

INTRODUCTION

Barnyardgrass is one of the most problematic weeds in Arkansas rice production. In 2011, a survey was issued to Arkansas crop consultants and 68% of responses

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listed barnyardgrass as the most problematic weed in rice (Norsworthy et al., 2013). Barnyardgrass alone can cause rice grain yield reductions of 70% if allowed to interfere with the crop throughout the growing season (Smith, 1988).

By the early 1990s, propanil-resistant barnyardgrass began to infest Arkansas rice fields (Carey et al., 1995). During the 1990s, 98% of Arkansas rice received at least one application of propanil. Continued repetition of propanil as the only means of post-emergence (POST) weed control quickly resulted in barnyardgrass evolving resistance to this herbicide (Carey et al., 1995). Today, barnyardgrass populations exist with resistance to propanil, quinclorac, clomazone, and imazethapyr in Arkansas rice (Talbert and Burgos, 2007; Norsworthy et al., 2013). With high levels of resistance evolving, new technologies are needed to help minimize or decrease the evolution of resistance within barnyardgrass and other troublesome weeds such as red rice (*Oryza sativa*). A new herbicide-resistant rice technology is being developed by BASF that will allow applications of Provisia (quizalofop), an ACCase-inhibiting herbicide, to be used.

Currently, Clincher and Ricestar HT are ACCase-inhibiting herbicides recommended and registered for grass control in rice (Scott et al., 2014). Clincher and Ricestar HT can be tank mixed with other contact rice herbicides to provide broad-spectrum broadleaf and grass control in rice without negatively effecting yield (Talbert et al., 2003). Acetyl-coenzyme A carboxylase-inhibiting herbicides like Provisia, Clincher, and Ricestar HT are commonly used graminicides that are systemic whereas Sharpen, a protoporphyrinogen oxidase (PPOase)-inhibiting herbicide, mainly controls broadleaf weeds. It has been reported that when mixing a PPOase-inhibiting herbicide like Aim (carfentrazone), a current POST option for broadleaf control in Arkansas rice, with imazethapyr provided an increase in weed control and resulted in a higher yield than imazethapyr alone (Zhang et al., 2006; Montgomery et al., 2015). Also, Sharpen is an emulsifiable concentrate (EC) herbicide formulation and an increase in crop or weed response can be oberserved when compared with other formulations of the same herbicide (Fish et al., 2014; Montgomery et al., 2015).

To achieve effective control of both grass and broadleaf weeds, the evaluation of combinations between herbicides is often based on Colby's method using Equation 1:

$$E = A + B - \frac{(A - B)}{100} \qquad \text{Eq. 1}$$

where E is the expected response when herbicides A and B are mixed, A is the efficacy obtained with one herbicide alone, and B is the efficacy of the other herbicide when applied alone (Colby, 1967). When the observed response is statistically greater than the calculated expected response, the particular herbicide combination is synergistic. The inverse response shows the herbicide combination to be antagonistic. If the expected value and observed values do not differ, the herbicide combination is deemed additive (Colby, 1967). When tank-mixed with Newpath (imazethapyr), a systemic herbicide, Sharpen can cause antagonism on grass weed control due to the rapid degradation of plant cell membranes (Camargo et al., 2012).

PROCEDURES

A study to evaluate the interaction of Sharpen tank-mixed with other rice herbicides on barnyardgrass control was conducted in the summer of 2015 at the University of Arkansas System Division of Agriculture Pine Tree Research Station near Colt, Ark. Provisia rice was drill-seeded at a rate of 20 seed/ft of row in 7-inch-wide rows into 6 × 17 ft plots. Treatments consisted of two rates of Sharpen at 0.5 and 1 fl oz/acre. Rice herbicides were applied at 1/2× and 1× rates alone and tank-mixed with both rates of Sharpen, which included Clincher (cyhalofop) at 7.5 oz/acre and 15 oz/acre, Ricestar HT (fenoxaprop) 12 oz/acre and 24 oz/acre, and Provisia (quizalofop) at 10.34 oz/acre and 20.68 oz/acre. All treatments included crop oil concentrate (COC) at 1% v/v. Applications were applied using a CO_2-pressurized backpack sprayer calibrated to deliver 15 gal/acre.

Treatments were arranged in a randomized complete block design with 3 factors: herbicide, rate, and the addition of Sharpen. Applications were made once barnyardgrass reached the 3- to 4-lf growth stage. Data collection included visual assessments of rice injury and weed control at 7, 14, and 21 days after treatment (DAT). Ratings were made on a 0 to 100 scale, with 0 being no crop injury or no weed control and 100 being complete crop death or complete control. All data were analyzed using JMP Pro 12 (SAS Institute Inc., Cary, N.C.), and means were separated using Fisher's protected least significant difference test ($P < 0.05$).

RESULTS AND DISCUSSION

For injury, there were no significant interactions between factors, but there was a main effect with the addition of Sharpen at 7 DAT. With the addition of Sharpen, injury averaged across all other treatments was 7%, whereas treatments without Sharpen averaged 4% injury (data not shown). By 14 DAT, main effects of herbicide and rate were significant. Both Ricestar HT and Provisia caused 4% injury while Clincher caused <1% injury (data not shown). The main effect of rate was significant, which would be expected because applying higher rates of herbicide can result in an increase in injury. By 21 DAT, injury had dissipated to 0% for all treatments (data not shown). The observed injury is similar to that reported by Montgomery et al. (2015) where <10% injury was observed when applying Sharpen POST in rice.

There were no significant interactions for the control of barnyardgrass, but the main effects of herbicide and the addition of Sharpen were significant. Treatments containing Sharpen alone averaged 94% and 89% control at 7 and 14 DAT, respectively (data not shown). By 14 DAT, only the main effect of herbicide was significant, with Ricestar HT and Provisia both providing 96% control and Clincher providing 89% control (data not shown).

The interaction of herbicide tank-mixtures using Colby's method showed that there was significance for certain tank-mixtures (Table 1). By 7 DAT, Sharpen alone provided 94% control (data not shown). Clincher at 7.5 oz/acre + Sharpen at 0.5 oz/

acre provided 89% control, and the expected control obtained from Colby's method was 99%, resulting in the combination being deemed antagonistic (Table 1). All other treatments were additive. By 14 DAT, Clincher at 7.5 oz/acre + Sharpen 0.5 oz/acre was antagonistic along with Ricestar HT at 24 oz/acre + Sharpen 1 oz/acre. As for other tank mixtures, treatments showed only additive effects. The occurrence of antagonism was not surprising because the response often occurs when systemic and contact herbicides are tank-mixed (Myers and Coble 1992; Zhang et al. 2005).

SIGNIFICANCE OF FINDINGS

The significance of this research is that growers may attempt to tank-mix Sharpen with graminicides to achieve a high level of control of both broadleaves and grasses. Unfortunately, antagonism was sometimes observed when mixing Sharpen with graminicides based on Colby's method. However, it should be noted that barnyardgrass control was never reduced by mixing a graminicide with Sharpen, but rather control was not as high as expected based on Colby's method. Growers should remember that a high level of control is needed for barnyardgrass or else the likelihood of this weed to develop resistance to the ACCase-inhibiting herbicides is high.

ACKNOWLEDGMENTS

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Table 1. Barnyardgrass control 7 and 14 days after treatment (DAT), including the observed values from the field and the expected value provided by Colby's method.

	7 DAT		14 DAT	
Herbicide tank-mixtures[a]	**Expected**	**Observed**	**Expected**	**Observed**
1/2× Rate				
Clincher 7.5 oz/acrecre + Sharpen 0.5 oz/acre	99	89b*[b]	99	84*
Ricestar HT 12 oz/acre + Sharpen 0.5 oz/acre	91	97	100	93
Provisia 10.34 oz/acre + Sharpen 0.5 oz/acre	100	94	99	98
1× Rate				
Clincher 15 oz/acre + Sharpen 1 oz/acre	84	90	99	92
Ricestar HT 24 oz/acre + Sharpen 1 oz/acre	100	98	100	97*
Provisia 20.68 oz/acre + Sharpen 1 oz/acre	100	99	100	97

[a] All treatments contained COC 1 % v/v at 1 qt/acre.

[b] For a given herbicide tank-mixture, an asterisk indicates a significant student *t*-test for comparing Expected and Observed values according to Colby's method.

Obey and Command Herbicide Programs

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

ABSTRACT

Barnyardgrass and Amazon sprangletop are two of the most troublesome grass weeds in rice production in Arkansas. With resistance to propanil and quinclorac becoming more prevalent across Arkansas, especially in barnyardgrass, other herbicides with different mechanisms of action will have to be considered. An experiment was conducted on a Sharkey clay soil at the University of Arkansas System Division of Agriculture's Southeast Research and Extension Center at Monticello, Ark., to determine if the use of clomazone (Command®) alone or premixed with quinclorac, commonly known as Obey® (clomazone + quinclorac), will improve control of barnyardgrass and Amazon sprangletop in rice. Prior to the post-emergence (POST) applications, clomazone applied pre-emergence (PRE) at 0.8 lb ai/acre provided greater control of both grass weeds than most other programs at 7 days after the delayed pre-emergence (DPRE) application. Throughout the remainder of the season, clomazone PRE at 0.8 lb ai/acre followed by (fb) Prowl H_2O (pendamethalin) + Ricebeaux (propanil+thiobencarb) at the 4- to 5-lf stage of rice continued to provide > 90% control of both barnyardgrass and Amazon sprangletop; albeit, comparable to other programs that included clomazone + quinclorac applied PRE. Due to the increasing occurrence of barnyardgrass resistance to quinclorac POST, quinclorac appears to have a much better fit in rice when applied in combination with clomazone as a PRE application.

INTRODUCTION

Generally, Arkansas rice producers prefer to plant rice between mid-March and mid-May to increase the likelihood of achieving the highest percent of relative yield as well as controlling common rice weeds early in the season (Hardke et al., 2013). When producers fail to plant rice prior to 1 June, young rice has difficulty growing efficiently due to competition with troublesome grass weeds, most notably barnyardgrass and Amazon sprangletop. With resistance to propanil and quinclorac progressing

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throughout the state, other herbicide mechanisms of action must be relied upon. Since the early 2000s, clomazone (Command® 3ME) has been utilized on > 90% of rice acres in Arkansas (Norsworthy et al., 2007). Although clomazone-resistant barnyardgrass populations have been confirmed in Arkansas (Norsworthy et al., 2008), incorporating it as the foundation of a rice herbicide program with or without quinclorac, and in combination with pendimethalin (Prowl® H_2O), could provide effective control of the troublesome grass weeds.

PROCEDURES

An experiment was conducted in 2015 at the University of Arkansas System Division of Agriculture's Southeast Research and Extension Center at Monticello, Ark, to evaluate Command (clomazone) and Obey (clomazone + quinclorac) programs for controlling barnyardgrass and Amazon sprangletop in late planted rice. This experiment was setup in a randomized complete block design with four replications. Clearfield® 111 was planted on 15 June 2015 on a Sharkey clay soil at a planting rate of 90 lb/acre. Barnyardgrass and Amazon sprangletop seed were broadcast over the test site immediately after planting rice. Herbicide treatments were applied using a Mudmaster™ sprayer equipped with a compressed air pressurized multi-boom calibrated to deliver 12 gal/acre. Herbicide programs included clomazone at 0.4 or 0.8 lb ai/acre (PRE and POST), clomazone+quinclorac at 0.8 lb ai/acre (PRE and POST), Prowl H_2O (pendimethalin) at 0.95 lb ai/acre (DPRE and POST), and Ricebeaux (propanil + thiobencarb) at 4.5 lb ai/acre (POST, 4- to 5-lf rice). All clomazone + quinclorac POST treatments were applied with a crop oil concentrate at 1% v/v, while all propanil + thiobencarb treatments were applied with a non-ionic surfactant at 0.25% v/v. Weed control and crop injury were evaluated on a scale of 0 to 100% control, where 0 equals no control and 100 equals complete control. Data were subjected analysis of variance and means were separated using Fisher's protected least significant difference test ($P = 0.05$).

RESULTS AND DISCUSSION

No crop injury was observed following any application (data not shown). Prior to the POST applications, clomazone at 0.4 lb ai/acre PRE fb pendamethalin DPRE and clomazone at 0.8 lb/acre PRE were the only treatments to provide > 92% control of both grass species 7 days after the DPRE application (Table 1). At 19 days after the POST application, clomazone at 0.8 lb ai/acre fb pendamethalin plus propanil + thiobencarb provided 98% and 99% control of barnyardgrass and Amazon sprangletop, respectively (Table 2). Additional programs that provided > 95% control of both species included clomazone + quinclorac PRE fb clomazone at 0.4 lb ai/acre + propanil + thiobencarb POST and clomazone + quinclorac PRE fb pendamethalin DPRE fb propanil + thiobencarb POST. By 34 days after the POST application, a slight reduction in control was observed for most treatments; however, the same previous treatments continued to provide > 90% control of both species (Table 3). Additionally, clomazone + quinclorac

at 0.8 lb ai/acre PRE fb clomazone at 0.4 lb ai/acre + pendamethalin + propanil + thiobencarb POST provided comparable control of barnyardgrass and Amazon sprangletop, with 93% and 92% control, respectively.

SIGNIFICANCE OF FINDINGS

Throughout the course of the season, clomazone at 0.8 lb/acre PRE fb pendamethalin + propanil + thiobencarb POST provided excellent control of both barnyardgrass and Amazon sprangletop; albeit, control was comparable to most of the other herbicide programs evaluated. It can be concluded from these data, that the use of clomazone alone or in combination with quinclorac (Obey) as the foundation of a rice herbicide program is capable of providing effective control of these problematic grass species in late planted rice. The results also indicate that in order to obtain complete control of barnyardgrass and Amazon sprangletop, producers should consider overlapping residual herbicides through use of PRE, DPRE, and EPOST timings.

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Table 1. Barnyardgrass and Amazon sprangletop control at 7 days after the delayed pre-emergence application.

Program[a]	Rate(s)	Application timing	Barnyard-grass	Amazon sprangletop
	(lb ai/acre)	----------	(%)	----------
Nontreated control	----	----	0	0
Clomazone	0.4	PRE	46	49
Clomazone + quinclorac	0.8	PRE	83	87
Clomazone fb	0.4	PRE		
pendamethalin	0.95	DPRE	98	98
Clomazone fb	0.4	PRE		
pendamethalin	0.95	DPRE	92	95
Clomazone	0.4	PRE	44	44
Clomazone + quinclorac	0.8	PRE	81	83
Clomazone + quinclorac fb	0.8	PRE		
pendamethalin	0.95	DPRE	93	93
Clomazone	0.4	PRE	51	51
Clomazone	0.4	PRE	14	14
Clomazone	0.8	PRE	97	98
Clomazone + quinclorac	0.8	PRE	88	90
LSD (P = 0.05)			23	24

[a] PRE = pre-emergence; DPRE = delayed pre-emergence; fb = followed by.

Table 2. Barnyardgrass and Amazon sprangletop control at 19 days after the post-emergence application.

Program[a]	Rate(s)	Application timing	Barnyard-grass	Amazon sprangletop
	(lb ai/acre)	----------	(%)	----------
Nontreated control	----	----	0	0
Clomazone fb	0.4	PRE		
clomazone + quinclorac	0.8	POST (4-5 lf)	0	0
Clomazone + quinclorac fb	0.8	PRE		
clomazone	0.4	POST (4-5 lf)	25	0
Clomazone fb	0.4	PRE		
pendamethalin fb	0.95	DPRE		
clomazone + quinclorac	0.8	POST (4-5 lf)	95	91
Clomazone fb	0.4	PRE		
pendamethalin fb	0.95	DPRE		
propanil + thiobencarb	4.5	POST (4-5 lf)	89	94
Clomazone fb	0.4	PRE		
propanil + thiobencarb	4.5	POST (4-5 lf)	94	93
Clomazone + quinclorac fb		0.8	PRE	
clomazone +	0.4	POST (4-5 lf)		
propanil + thiobencarb	4.5		98	96
Clomazone + quinclorac fb	0.8	PRE		
pendamethalin fb	0.95	DPRE		
propanil + thiobencarb	4.5	POST (4-5 lf)	97	96
Clomazone fb	0.4	PRE		
propanil + thiobencarb	4.5	POST (4-5 lf)	89	84
Clomazone fb	0.4	PRE		
clomazone +	0.4	POST (4-5 lf)		
propanil + thiobencarb	4.5		97	85
Clomazone fb	0.8	PRE		
pendamethalin +	0.95	POST (4-5 lf)		
propanil+thiobencarb	4.5		98	99
Clomazone + quinclorac fb	0.8	PRE		
clomazone +	0.4	POST (4-5 lf)		
pendamethalin +	0.95			
propanil + thiobencarb	4.5		97	94
LSD (*P* = 0.05)			20	7

[a] DPRE = delayed pre-emergence; fb = followed by; PRE = pre-emergence; POST = post-emergence.

Table 3. Barnyardgrass and Amazon sprangletop control at 34 days after the post-emergence application.

Program[a]	Rate(s)	Application timing	Barnyard-grass	Amazon sprangletop
	(lb ai/acre)	----------	(%)	----------
Nontreated control	----	----	0	0
Clomazone fb	0.4	PRE		
clomazone + quinclorac	0.8	POST (4-5 lf)	97	10
Clomazone + quinclorac fb	0.8	PRE		
clomazone	0.4	POST (4-5 lf)	44	6
Clomazone fb	0.4	PRE		
pendamethalin fb	0.95	DPRE		
clomazone + quinclorac	0.8	POST (4-5 lf)	89	74
Clomazone fb	0.4	PRE		
pendamethalin fb	0.95	DPRE		
propanil + thiobencarb	4.5	POST (4-5 lf)	86	91
Clomazone fb	0.4	PRE		
propanil + thiobencarb	4.5	POST (4-5 lf)	81	89
Clomazone + quinclorac fb	0.4	PRE		
clomazone +	4.5	POST (4-5 lf)		
propanil + thiobencarb	4.5		95	95
Clomazone + quinclorac fb	0.8	PRE		
pendamethalin fb	0.95	DPRE		
propanil + thiobencarb	4.5	POST (4-5 lf)	94	95
Clomazone fb	0.4	PRE		
propanil + thiobencarb	4.5	POST (4-5 lf)	81	86
Clomazone fb	0.4	PRE		
clomazone +	0.4	POST (4-5 lf)		
propanil + thiobencarb	4.5		76	89
Clomazone fb	0.8	PRE		
pendamethalin +	0.95	POST (4-5 lf)		
propanil + thiobencarb	4.5		94	95
Clomazone + quinclorac fb	0.8	PRE		
clomazone +0.4	POST (4-5 lf)			
pendamethalin +	0.95			
propanil + thiobencarb	4.5		93	92
LSD (*P* = 0.05)			21	13

[a] DPRE = delayed pre-emergence; fb = followed by; PRE = pre-emergence; POST = post-emergence.

Optimizing Quizalofop Rate Structure for Sequential Application in Provisia™ Rice

Z.D. Lancaster[1], J.K. Norsworthy[1], S.M. Martin[1], M.L. Young[1], R.C. Scott[2], and L.T. Barber[2]

ABSTRACT

The BASF Corporation is currently developing a new non-genetically modified organism (GMO) rice trait (Provisia™ rice) that will be resistant to quizalofop, an acetyl coenzyme A carboxylase (ACCase)-inhibiting herbicide. An experiment was conducted in the summer of 2014 and 2015 at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC) near Stuttgart, Ark., to determine the best rate structure for sequential applications of quizalofop when the first application was made at either the 2-lf or 6-lf stage of grasses. The experiment was set up as a two factor, randomized complete block design with factor-A being the growth stage at first application and factor-B being the rate structure of quizalofop. Herbicide rate structures were 10.3, 15.5, or 20.6 fl oz/acre followed by 10.3, 15.5, or 20.6 fl oz/acre sequential application 14 days after the initial application. The total amount of quizalofop applied in a rate structure never exceeded 31 fl oz/acre; hence, some combinations were excluded. In 2014, the greatest control of both barnyardgrass and broadleaf signalgrass was achieved when quizalofop was sequentially applied at the 15.5 followed by 15.5 fl oz/acre rates, resulting in 99% and 98% control, respectively. The sequential 10.3 followed by 10.3 fl oz/acre quizalofop treatment had significantly less barnyardgrass and broadleaf signalgrass control. In 2015, there were no significant differences among herbicide rates. Control for barnyardgrass and broadleaf signalgrass was reduced by making the first quizalofop application on 6-lf grass compared to 2-lf grass for 2014, and the same effect was observed for red rice in 2015. Based on these results, the most likely recommended rate structure for quizalofop will be 15.5 fl oz/acre on 2-lf grasses followed by a subsequent application at approximately 14 days after the initial application.

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INTRODUCTION

Rice is one of the most important crops grown in Arkansas, with a major obstacle to rice production being weed control. Weeds compete with rice for sunlight, water, nutrients, and other growth requirements (Smith, 1988). In a 2011 survey, 63% of Arkansas crop consultants listed barnyardgrass (*Echninochloa crus-galli*) as the most problematic weed of rice, with red rice (*Oryza sativa*) ranking second (Norsworthy et al., 2013). Red rice and barnyardgrass can potentially cause yield losses as high as 82% and 70%, respectively (Smith, 1988).

Barnyardgrass has evolved resistance to multiple herbicides used in Arkansas rice, the first of which was propanil in the early 1990s (Carey et al., 1995). Poor stewardship of alternative herbicides led to continued herbicide resistance of barnyardgrass to quinclorac, clomazone, and the imidazolinone herbicides used in Clearfield™ rice (Talbert and Burgos, 2007; Norsworthy et al., 2013). With the evolution of weeds that have resistance to multiple herbicide modes of action, weed control has increasingly become more challenging in Arkansas rice production systems. A new technology is needed to control many of these troublesome weeds. The BASF Corporation is currently developing a new herbicide-resistant rice technology that will allow for topical applications of quizalofop, an acetyl coenzyme A carboxylase (ACCase)-inhibiting herbicide. Quizalofop will be primarily used in the Provisia™ rice system to control barnyardgrass, red rice, and other annual grass weeds. With the anticipated launch of Provisia rice within the next 2 to 3 years, research is needed to understand the best fit for this technology in Arkansas rice production systems.

PROCEDURES

An experiment was conducted to determine the best rate structure of sequential applications of quizalofop to Provisia rice, when applied initially to either 2- or 6-lf grass. The field experiment was conducted in the summer of 2014 and 2015 at the RREC near Stuttgart, Ark., on a Dewitt silt-loam soil. The experiment was set up as a two factor factorial, randomized complete block design having four replications with factor-A being the growth stage at first application and factor-B being the rate structure of quizalofop. Provisia rice was planted on 7 inch rows, in 6 × 20 ft plots, with a typical rate of 22 seeds/foot of row. Treatments of quizalofop were applied to a natural population of weeds. Sequential applications of quizalofop were applied, with the second application being made 14 days after the first application. All quizalofop applications were made at 15 gallons of spray solution per acre with a crop oil concentrate added at 1% v/v to all treatments. Broadleaf weeds and sedges were controlled by over-spraying the test site with 2,4-D and halosulfuron (Permit®). The quizalofop rate structure for this experiment was 10.3, 15.5, or 20.6 fl oz/acre (first application) followed by a sequential application of 10.3, 15.5, or 20.6 fl oz/acre. All combinations were evaluated that allowed for no more than the maximum anticipated rate of 31 fl oz/acre to be applied over both applications. For instance, 20.6 fl oz/acre followed by 15.5 or 20.6 fl oz/acre was not evaluated because the total amount of herbicide exceeded the anticipated allowable

maximum (John Harden, BASF corp). Observations were taken on weed control with 0 being no control and 100 being complete weed control. In 2014, weed control ratings were taken for barnyardgrass and broadleaf signalgrass, and in 2015, ratings were taken for barnyardgrass, broadleaf signalgrass, and red rice. All data were subjected to analysis of variance using JMP 12.1, and means were separated using Fisher's protected least significant difference test ($P = 0.05$).

RESULTS AND DISCUSSION

In 2014, there was not a significant rate structure by growth stage interaction, but there were significant main effects for rate structure and growth stage for both barnyardgrass and broadleaf signalgrass control. The highest numerical control for barnyardgrass was produced with the 15.5/15.5 fl oz/acre rate structure of 98%, but was only significantly different from the 80/80 g ai/ha structure which resulted in 89% control (Fig. 1). Likewise, the highest numerical control for broadleaf signalgrass was produced with the 15.5/15.5 fl oz/acre rate structure at 99%, but again was only significantly different from the 10.3/10.3 fl oz/acre structure which resulted in 91% control. For barnyardgrass, when the initial application of quizalofop was made at the 2-lf growth stage it resulted in 98% control, averaged over rates; but when the application was initiated at the 6-lf growth stage, control declined to 87% (Fig. 2). For broadleaf signalgrass when the initial application was made at the 2-lf stage, control averaged 98% over application rates; whereas control averaged 95% when the initial application was delayed until the 6-lf stage.

In 2015, weed density was less than in 2014 and results slightly differed from the previous year. Only the main effect for growth stage of initial application was significant for red rice control in 2015. When quizalofop was initially applied at the 2-lf growth stage, red rice control averaged 99% (Fig. 3). Delaying the application to the 6-lf growth stage resulted in average red rice control of 97%. For barnyardgrass and broadleaf signalgrass, comparable levels of control were obtained across all application timings and rate structures (data not shown). The lower density of grasses in 2015 likely contributed to the inability to separate experimental treatments because herbicides are often more efficacious as weed density decreases.

SIGNIFICANCE OF FINDINGS

The significance of this research is that the 15.5 followed by 15.5 fl oz/acre rate provides excellent control of barnyardgrass, broadleaf signalgrass, and red rice (> 97%) when applied to small, actively growing grasses. A residual herbicide is likely to be needed at planting first to remove some of the selection pressure placed on quizalofop for resistance, especially barnyardgrass. Secondly by lowering the density of grass weeds, present growers should have more flexibility in timing the initial quizalofop application.

ACKNOWLEDGMENTS

Funding and support for this research provided by the Arkansas Rice Research and Promotion Board, and the University of Arkansas System Division of Agriculture is gratefully appreciated. Appreciation is also expressed to BASF for their cooperation and support of this project.

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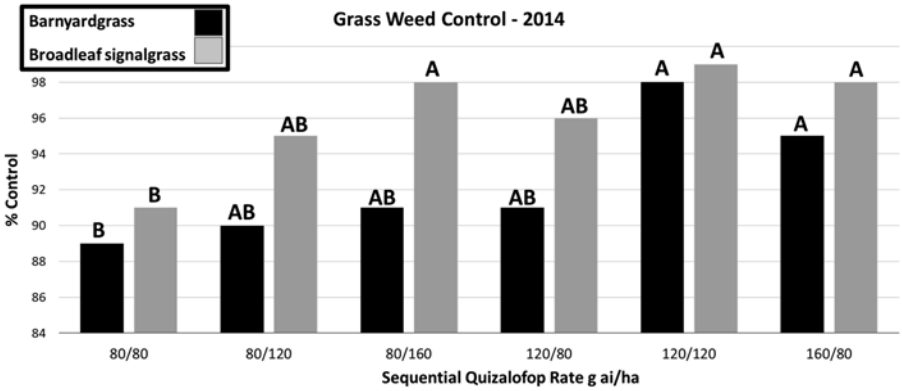

Fig. 1. Main effect of quizalofop rate structure with first rate applied followed by (/) second rate applied on barnyardgrass and broadleaf signalgrass control, averaged over application timings in 2014. Letters used to separate means within grass weed species (*P* = 0.0092).

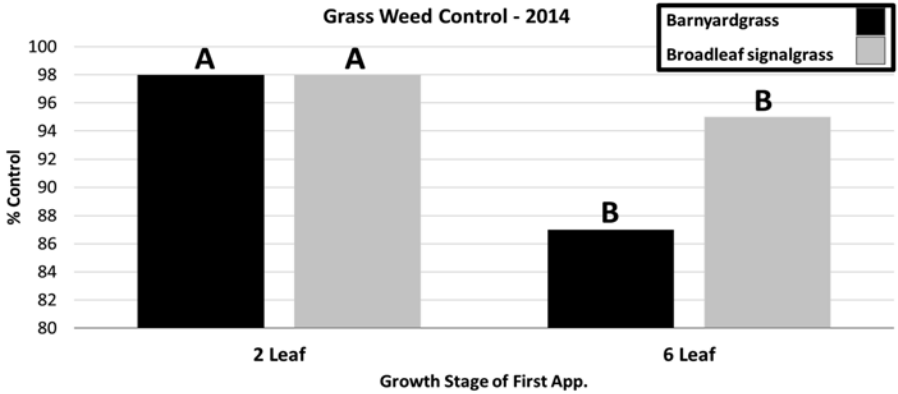

Fig. 2. Main effect of grass growth stage at initial application of quizalofop on barnyardgrass and broadleaf signalgrass control, averaged over sequential rates in 2014. Letters used to separate means within grass weed species (*P* = 0.0215).

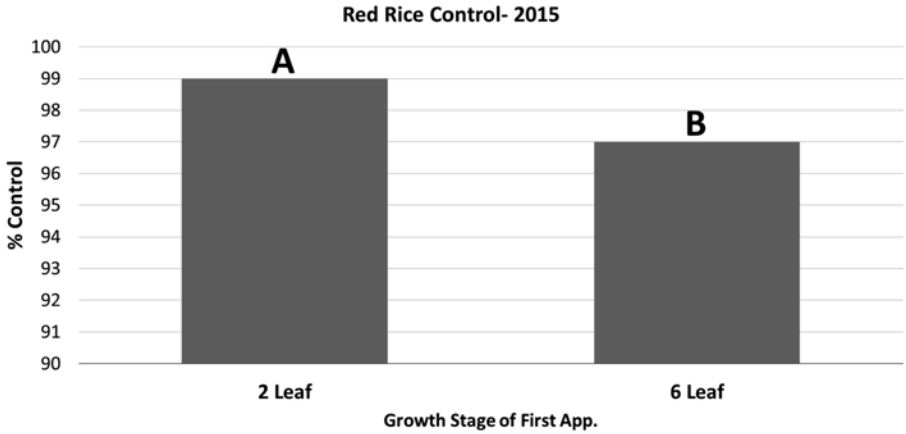

Fig. 3. Main effect for growth stage on red rice control with quizalofop, averaged over sequential rates in 2015 (*P* = 0.0403).

Effects of CruiserMaxx® Rice on Rice Tolerance to Pre-Emergence Herbicides

S.M. Martin[1], J.K. Norsworthy[1], R.C. Scott[2], G.M. Lorenz[3], and J.T. Hardke[4]

ABSTRACT

Historically, some herbicide and insecticide interactions have proven beneficial whereas others have been detrimental to certain crops. In-furrow applications of insecticides have proven to be beneficial in cotton production with clomazone (Command®) receiving a label in cotton under restrictions that an in-furrow application of insecticide such as disulfoton or phorate be used. However, when some insecticides are used in conjunction with propanil, significant rice injury can occur. With recent evidence that insecticide seed treatments can reduce injury in rice from drift events, a field study was developed to test different pre-emergence herbicides for safened use in rice with the addition of insecticide seed treatments. This study was conducted at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC) near Stuttgart, Ark., and at the University of Arkansas Pine Bluff Farm (UAPB) near Lonoke, Ark., in 2014 and 2015. CruiserMaxx® Rice was used to evaluate different pre-emergence herbicides for safened use in rice production. At 3 weeks after planting (WAP), the clomazone standard had significantly more plants emerge than all other treatments. By 4 WAP, fluridone- and thiobencarb-treated plots had similar injury amounts to the clomazone standard. Clethodim- and thiobencarb-treated plots yielded similar to the clomazone-treated plots with yields ranging from 163 to 180 bu/acre. When averaged across herbicide treatments, the CruiserMaxx Rice treated seed provided 9% to 10% less injury and a 9% yield increase over the fungicide-only treated rice. In conclusion, clethodim and thiobencarb gained interest as possible options for pre-emergence use in rice along with CruiserMaxx Rice which provided a proven benefit to the rice crop.

INTRODUCTION

One of the major obstacles in rice production is weed control which in recent years has become a major problem due to resistance in some of the most problematic weeds

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in rice. Some of these problematic weeds in Arkansas rice are barnyardgrass and red rice, which can cause yield losses of up to 80% (Norsworthy et al., 2013; Smith, 1988).

Clomazone is commonly applied at or near planting to most of the Arkansas rice acreage for control of barnyardgrass and other grass weeds. Unfortunately, populations of barnyardgrass now exist in Arkansas with resistance to clomazone (Norsworthy et al., 2013). Additionally, barnyardgrass exhibits resistance to propanil, quinclorac, and acetolactate synthase (ALS)-inhibiting herbicides, making control options for this weed somewhat limited (Heap, 2016).

In addition to barnyardgrass, red rice has evolved resistance to ALS-inhibiting herbicides since the introduction of Clearfield® rice (Talbert and Burgos, 2007). With the two most problematic weeds in rice developing resistance to multiple herbicide modes of action, new modes of action are needed to combat these ongoing resistance problems. The last new mode of action to be commercialized in crops was discovered in the early 1980s; therefore, the best method to combat resistance would be to label an already existing herbicide that is not currently used in rice.

Previously, the use of insecticides has enabled the labeling of a herbicide in a crop that was sensitive in the absence of the insecticide. York et al. (1991) found that the addition of phorate or disulfoton used in-furrow in cotton would allow for clomazone herbicide to be safely used. Most recently, CruiserMaxx® Rice, a fungicide and insecticide seed treatment, has been proven to provide multiple benefits to the rice crop, including safening against low rates of glyphosate and imazethapyr (Scott et al., 2014). Additionally, CruiserMaxx Rice provides the expected benefits of insect control and overall better plant vigor (Wilf et al., 2010; Plummer et al., 2012).

PROCEDURES

An experiment was conducted to determine if the use of a CruiserMaxx Rice seed treatment could safen the crop against herbicides not currently labeled for preemergence use. Experiments were conducted at the University of Arkansas Pine Bluff Farm (UAPB) near Lonoke, Ark., and at the Rice Research and Extension Center (RREC) near Stuttgart, Ark., in the summers of 2014 and 2015. Both locations were planted with CL152 rice at a seeding rate of 75 lb/acre (approximately 20 seed/ft of row) in 7.5-inch-wide rows.

The study was organized using a randomized complete block design with four replications and two factors. Factor A, insecticide seed treatment, consisted of CruiserMaxx Rice (7 oz/cwt) and a fungicide-only check. Factor B consisted of pethoxamid (0.5 lb ai/acre), fluridone (0.2 lb ai/acre), pyroxasulfone (0.1 lb ai/acre), S-metolachlor (0.955 lb ai/acre), thiobencarb (6 lb ai/acre), clethodim (0.12 lb ai/acre), quizalofop (0.106 lb ai/acre), and clomazone (0.6 lb ai/acre), the current standard, all applied immediately after planting at 15 gal/acre. The plots were kept weed-free with standard rice herbicides and all production practices followed University of Arkansas System Division of Agriculture's Cooperative Extension Service (CES) recommendations throughout the season.

Data collection included stand counts, injury estimates, and rough-rice grain yield. Data were subjected to analysis of variance using JMP Pro 11 (SAS Institute Inc., Cary,

N.C.) with site years and replications considered random effects. Seed treatments and herbicides were considered fixed effects. Fisher's protected least significant difference test was used to separate means ($P < 0.05$).

RESULTS AND DISCUSSION

Rice in all plots emerged 1 to 2 weeks after planting (WAP), and stand counts were taken 3 WAP. There was no significant interaction between the effects of seed treatment and herbicide for rice stands; but rather only main effects were significant. The use of CruiserMaxx Rice did provide an increase of 17% in rice emergence when averaged across all herbicides. Averaged over seed treatments, the standard clomazone treatment had 11.5 plants/ft of row, which was significantly greater than stands in all other treatments (Table 1). Fluridone- and thiobencarb-treated plots had the next highest density, with stands of 1.5 to 2.0 plants/ft of row less than clomazone.

By 4 WAP, visual injury symptoms began to occur in all plots along with thinned stands in some treatments. All treatments had some injury including the standard clomazone treatment. Clomazone-, thiobencarb-, and fluridone-treated plots had the least amount of injury at 17%, 23%, and 23%, respectively (Table 1). S-metolachlor and pyroxasulfone had 75% or more injury at 4 WAP, mainly due to reduced rice stands. Injury at 8 WAP began to show more differences. S-metolachlor and pyroxasulfone remained the most injured with at least 90% visual injury. Fluridone-treated plots had not recovered from injury while the clomazone-treated plots had only 9% injury at 8 WAP (Table 1). Also averaged across herbicides, the CruiserMaxx Rice plots were 9% to 10% less injured than the fungicide-only treatments at both 4 and 8 WAP.

Clomazone remained the highest yielding treatment along with thiobencarb and clethodim with yields ranging from 163 to 180 bu/acre (Table 1). All treatments with the exception of S-metolachlor and pyroxasulfone had grain yields of over 140 bu/acre. In addition, the CruiserMaxx Rice provided a 9% yield increase over the fungicide-only treatments across all herbicides.

SIGNIFICANCE OF FINDINGS

Thiobencarb is labeled in rice as a delayed pre-emergence treatment; however, it is not labeled for pre-emergence use because rice stands can be reduced as observed in this research. The level of safening from the CruiserMaxx Rice seed treatment could possibly allow for thiobencarb to be applied as a pre-emergence application. Overall, the CruiserMaxx Rice seed treatment did slightly safen the rice to non-labeled herbicides; albeit, the safening was not sufficient for commercial use of most evaluated herbicides. However, some herbicides identified in this research would warrant further evaluations.

Clethodim can be used in rice currently for burndown applications, but has a 30-day plant back interval which possibly could be shortened if rice seed is treated with CruiserMaxx Rice. Pethoxamid is also a potential candidate for further evaluation in rice, especially timings other than at planting.

Although there were no significant interactions between herbicides and the CruiserMaxx Rice for any of the evaluated parameters, CruiserMaxx Rice did provide several noticeable benefits to the rice crop. CruiserMaxx Rice provided about a 10% increase in yield and reduced overall injury at each rating. With these added benefits along with those identified in previous research such as safening from herbicide drift, increased plant vigor and insect control (Wilf et al., 2010; Plummer et al., 2012; Scott et al., 2014), CruiserMaxx Rice should become a staple component of Arkansas rice production.

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Table 1. Effect of various herbicides applied immediately after planting CL152 rice on plant density, visible estimates of injury, and rough-rice grain yield averaged over seed treatments.

Treatment	Density[a]	Injury 4 WAP[b]	Injury 8 WAP	Yield (relative yield)[c]
	(plants/10 row ft)	----------(%)	----------	[bu,acre (%)]
Clomazone	115	17	9	180 (100)
Pethoxamid	65	60	44	144 (80)
Fluridone	97	23	25	143 (79)
Pyroxasulfone	53	75	90	43 (24)
S-metolachlor	44	78	93	43 (24)
Thiobencarb	94	23	17	163 (91)
Clethodim	73	39	29	164 (91)
Quizalofop	70	40	35	146 (81)
LSD	14	12	11	19

[a] Density measured for 10 feet of row 3 WAP.
[b] WAP = weeks after planting.
[c] Relative yield compared to the current standard of clomazone.

Evaluation of Provisia™ Herbicide Tank Mixtures

M.S. McCown[1], L.T. Barber[2], J.K. Norsworthy[1], Z.D. Lancaster[1], J. Green[1], and M.R. Miller[1]

ABSTRACT

The BASF Corporation is currently developing a new non-genetically modified (GMO) rice trait that will be resistant to quizalofop, an acetyl coenzyme A carboxylase (ACCase)-inhibiting herbicide. Along with this new trait, BASF will be marketing the herbicide quizalofop under the tradename Provisia™. An experiment was conducted in 2015 at the University of Aransas System Division of Agriculture's Southeast Research and Extension Center (SEREC) in Monticello, Ark., and at the Rice Research and Extension Center (RREC) near Stuttgart, Ark., to evaluate early post-emergence (EPOST) tank mixtures containing Provisia herbicide in Provisia rice. In this study, nine common rice herbicides were evaluated in combination with Provisia herbicide for weed control and crop tolerance. Tank mixture candidates included: quinclorac (Facet®), pendimethalin (Prowl® H_20), saflufenacil (Sharpen®), carfentrazone (Aim®), penoxsulam (Grasp®), bispyribac-sodium (Regiment®), halosulfuron (Permit®), propanil + quinclorac (Duet®), and propanil + thiobencarb (Ricebeaux®). All treatments were applied at the 1- to 3-lf stage of rice (EPOST) and followed by (fb) quizalofop (Provisia) applied prior to flooding (PREFLD). As a result of some tank mixes (Aim or Sharpen), slight injury was observed on Provisia rice at both locations; however, no more than 10% injury was observed with any tank mixture. At 22 days after EPOST applications, adequate control of barnyardgrass was seen in those tank mixes that contained more than one mode of action; however, these differences were no longer present 10 days following the mid-POST application. Similarly, Amazon sprangletop control increased when a tank mix was made with Provisia herbicide. At SEREC, antagonism was observed when propanil + quinclorac was mixed with Provisia, with no more than 60% control of barnyardgrass or Amazon sprangletop being observed. Red rice control at SEREC was >89% with all tank mixtures and Provisia alone after the first application and 99% control after the second application timing. Red rice control at RREC was 75% to 90% after the first application. The two application timings were sufficient to provide 99% control of all off-type rice cultivars. We conclude that having a tank-mix partner with Provisia herbicide is beneficial in controlling weedy grasses and red rice.

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INTRODUCTION

Weed control is continuing to be a major obstacle in rice production. In a 2011 survey, 63% of Arkansas crop consultants listed barnyardgrass as the most problematic weed of rice with red rice ranking second (Norsworthy et al., 2013). Red rice and barnyardgrass can potentially cause yield losses as high as 82% and 70%, respectively (Smith, 1988).

Barnyardgrass has evolved resistance to multiple herbicides used commonly in Arkansas rice, the first of which was propanil in the early 1990s (Carey et al., 1995). Poor stewardship of alternative herbicides led to continued herbicide resistance of barnyardgrass to quinclorac, clomazone, and the imidazolinione herbicides used in Clearfield rice (Talbert and Burgos, 2007; Norsworthy et al., 2013). With the evolution of weeds that have resistance to multiple herbicide modes of action, a new technology is needed to control many troublesome weeds. The BASF Corporation is currently developing a new herbicide-resistant rice technology that will allow for topical applications of quizalofop, an acetyl coenzyme A carboxylase (ACCase)-inhibiting herbicide. Quizalofop will be marketed as Provisia™ herbicide, and primarily used in the Provisia rice system to control barnyardgrass and red rice. With the anticipated launch of Provisia rice within the next 2 to 3 years, research is needed to understand the best fit for this technology in Arkansas rice production systems.

PROCEDURES

This experiment was designed to evaluate the potential of various tank mixtures that could be applied in a Provisia rice production system. The field experiment was conducted in 2015 at the Southeast Research and Extension Center in Monticello, Ark., and at the Rice Research and Extension Center near Stuttgart, Ark., to evaluate early postemergence (EPOST) tank mixtures containing Provisia herbicide in Provisia rice. The experiment was set up as a randomized complete block. Nine common rice herbicides were evaluated in combination with Provisia herbicide for weed control and crop tolerance. Tank mixture candidates included: quinclorac (Facet®) at 32 oz/acre (0.42 kg ai/ha), pendimethalin (Prowl® H_2O) at 15.4 oz/acre (1.12 kg ai/ha), saflufenacil (Sharpen®) at 0.75 oz/acre (0.0187 kg ai/ha), carfentrazone (Aim®) at 3.2 oz/acre (0.056 kg ai/ha), penoxsulam (Grasp®) at 2.4 oz/acre (0.042 kg ai/ha), bispyribac-sodium (Regiment®) at 0.93 oz/acre (0.052 kg ai/ha), halosulfuron (Permit®) at 1 oz/acre (0.052 kg ai/ha), propanil + quinclorac (Duet®) at 96 oz/acre (3.38 kg ai/ha), and propanil + thiobencarb (Ricebeaux®) at 96 oz/acre (5.04 kg ai/ha). All treatments contained crop oil concentrate at 1% volume per volume (v/v). Treatments were applied at the 1- to 3-lf stage of rice (EPOST) and followed by (fb) quizalofop (Provisia) applied prior to flooding (PRE-FLD). Visual observations were taken for crop injury and weed control on a scale of 0 to 100, with 0 being no injury or weed control and 100 being complete crop death or weed control. At both locations, weed control was evaluated on barnyardgrass and red rice. In addition, Amazon sprangletop was evaluated at SEREC. All data were processed using analysis of variance with JMP 12.1 (SAS Institute Inc., Cary, N.C.), and means were separated using Fisher's protected least significant difference test ($P = 0.05$).

RESULTS AND DISCUSSION

As a result of some tank mixes (Aim or Sharpen), slight injury was observed on Provisia rice at both locations; however, no more than 7% injury was observed with any tank mixture. Weed control was evaluated on barnyardgrass and red rice at both locations. In addition, Amazon sprangletop and some off-type rice cultivars were evaluated at the SEREC. At 22 days after the EPOST applications, the greatest barnyardgrass control was seen in those tank mixes that contained more than one mode of action, such as halosulfuron, at both locations (Figs. 1 and 2); however, these differences were no longer present 10 days following the mid-POST application. A similar response was observed for Amazon sprangletop where increased control was seen when a tank mix was made with Provisia (Fig. 3). At the SEREC, some antagonism was observed when propanil + quinclorac was mixed with Provisia, resulting in only 60% control of barnyardgrass or Amazon sprangletop (Figs. 2 and 3). The herbicide combinations with Provisia herbicide were more efficacious at SEREC than at RREC. At SEREC, >89% red rice control was observed with all tank mixtures and Provisia alone after the first application and 99% control after the second application (data not shown). At RREC, red rice control ranged from 75% to 90% after the first application (Fig. 4). After two applications, 99% control of red rice was observed with all treatments. From these results, we conclude that having a tank mixing partner with Provisia herbicide is beneficial in controlling weedy grasses and off-type rice cultivars, including red rice.

SIGNIFICANCE OF FINDINGS

The significance of this research is primarily to determine potential tank mix partners with Provisia herbicide to achieve complete weed control and reduce crop injury. The results from this experiment demonstrate that there is little or no risk of injury to Provisia rice from the herbicides evaluated. In addition, we can conclude that having a tank mix partner, such as Facet L + Prowl H_2O, with Provisia is beneficial in controlling broadleaf species, red rice, and troublesome grass weeds.

ACKNOWLEDGMENTS

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

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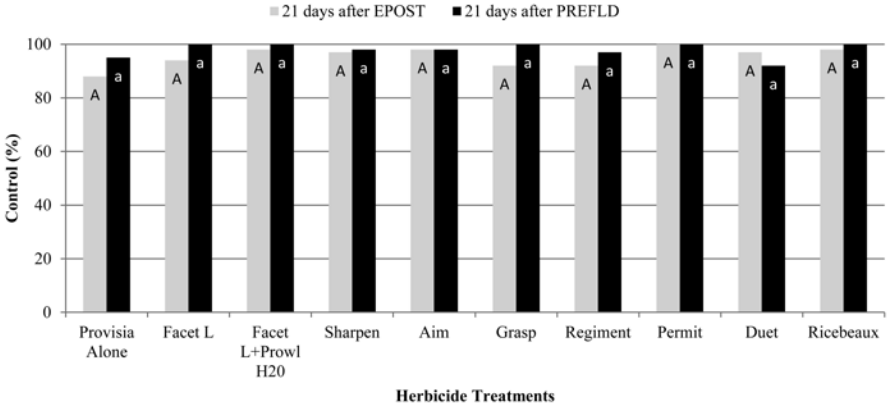

Fig. 1. Control of barnyardgrass visually rated 21 days after early post-emergence (EPOST) and 21 days following the preflood (PREFLD) application at the Rice Research and Extension Center near Stuttgart, Ark. Means followed by same letter do not significantly differ at *P* = 0.05.

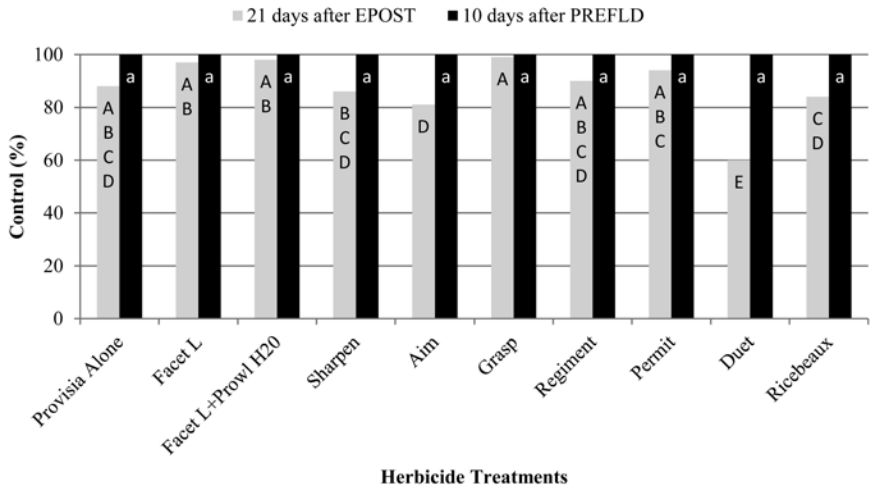

Fig. 2. Control of barnyardgrass visually rated 21 days following the early post-emergence (EPOST) applications and 10 days following the preflood (PREFLD) application at the Southeast Research and Extension Center near Monticello, Ark. Means followed by same letter do not significantly differ at *P* = 0.05.

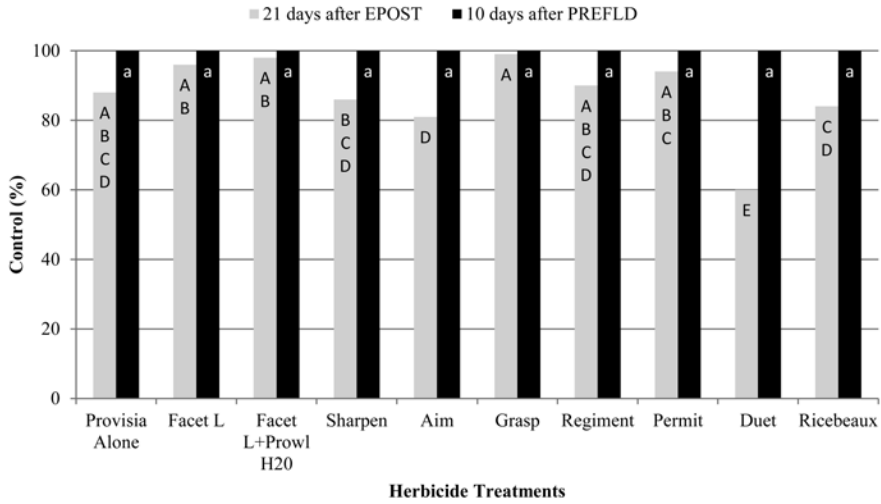

Fig. 3. Control of Amazon sprangletop visually rated 21 days following the early post-emergence (EPOST) applications and 10 days following the preflood (PREFLD) application at the Southeast Research and Extension Center near Monticello, Ark. Means followed by same letter do not significantly differ at *P* = 0.05.

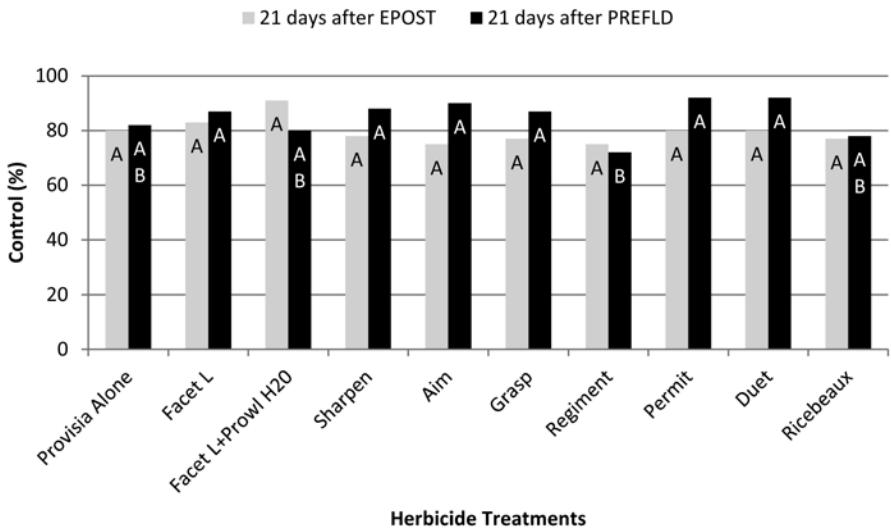

Fig. 4. Control of red rice visually rated 21 days following early post-emergence (EPOST) and 21 days following the preflood (PREFLD) application at the Rice Research and Extension Center near Stuttgart, Ark. Means followed by same letter do not significantly differ *P* = 0.05.

Influence of Herbicide Rate, Application Volume, and Adjuvant Use on Efficacy of Rinskor™ Active

M.R. Miller[1] and J.K. Norsworthy[1]

ABSTRACT

As the evolution of herbicide resistance continues, the development of a herbicide with a new active ingredient is needed. The introduction of Loyant™ herbicide with Rinskor™ Active brings a valuable new tool to weed control by providing an alternative mode of action for use in rice that provides broad-spectrum post-emergence control of broadleaf, grass, and sedge species. A field experiment was conducted in the summer of 2014 and repeated in 2015 to evaluate the influence of herbicide rate, spray volume, and adjuvant use on the efficacy of Rinskor on problematic weeds in rice. Factors included 0.015 and 0.03 lb ai/acre of Rinskor formulated as a soluble concentrate (SC) applied at three application volumes: 5, 10, and 20 gal/acre across four rates of methylated seed oil (MSO): 0, 16, 32, and 48 fl oz/acre. Weeds evaluated included barnyardgrass, hemp sesbania, yellow nutsedge, and Palmer amaranth planted in a non-flooded dryland setting. No significant differences were observed between years; therefore, years were combined. Rinskor at 0.03 lb/acre provided greater control than 0.015 lb/acre, regardless of spray volume or MSO rate, and control with 0.03 lb/acre improved as spray volume and MSO rate increased.

INTRODUCTION

Today, rice producers in the mid-southern United States face many challenges. Among these is achieving control of barnyardgrass which continues to be the most problematic weed in Arkansas rice (Norsworthy et al., 2013), and is historically one of the most problematic weeds in the world (Holm et al., 1997). The high level of competiveness and ever-present risk for the evolution of herbicide resistance makes barnyardgrass particularly concerning. Currently, barnyardgrass has evolved resistance to at least 9 sites of herbicide action worldwide and at least 7 sites of action in the United States (Heap, 2015). In Arkansas rice, barnyardgrass has evolved resistance to propanil, quinclorac, clomazone, and acetolactate synthase (ALS)-inhibiting herbicides (Lovelace et al., 2002; Norsworthy et al., 2009).

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Loyant™ herbicide with Rinskor Active™ (no common name is yet approved) is a new herbicide discovered by Dow AgroSciences and has potential for use in global rice culture. The compound will provide an alternative mode of action (MOA) in rice thereby providing effective control of propanil-, quinclorac-, clomazone-, and ALS-resistant barnyardgrass, ALS-resistant rice flatsedge, smallflower umbrella sedge, yellow nutsedge, and other troublesome weeds in rice.

PROCEDURES

A field experiment was conducted during 2014 and repeated in 2015 at the University of Arkansas System Division of Agriculture's Agricultural Experiment Station in Fayetteville, Ark., to determine efficacy of Rinskor. In both years, plots measured 10 ft × 20 ft and consisted of two rows each of barnyardgrass, hemp sesbania, and yellow nutsedge planted across the plots perpendicular to herbicide application. The site included a population of glyphosate-resistant (GR) Palmer amaranth. The experiment was arranged as a randomized complete block design with a three-factor factorial treatment structure and four replications. The first factor consisted of herbicide rate either 0.015 or 0.03 lb ai/acre of Rinskor Active formulated as a soluble concentrate (SC). The second factor consisted of three application volumes: 5, 10, and 20 gal/acre. The third factor consisted of three rates of methylated seed oil (MSO): 0, 16, 32, and 48 fl oz/acre. Treatments were applied at the 3- to 4-lf growth stage of all weed species. Herbicides were applied using a CO_2-pressurized backpack sprayer calibrated to deliver the appropriate application volume. In order to achieve the correct spray volume and similar droplet spectra, 11001 TT nozzles were used for 5 and 10 gal/acre, while 11002 TT were used to achieve 20 gal/acre of spray volume. Visual estimates for barnyardgrass, hemp sesbania, yellow nutsedge, and Palmer amaranth control were estimated on a scale of 0% to 100% with 0% representing no control and 100% representing complete control at 28 days after application. Data were subjected to analysis of variance (ANOVA) in JMP Pro 12 (JMP Pro 12, SAS Institute Inc., Cary, N.C.). Where the ANOVA indicated significance, means were separated using Fisher's protected least significant difference test ($P = 0.05$).

RESULTS AND DISCUSSION

No significant differences were observed between years; therefore, years were combined. The ANOVA indicated a significant three-way interaction between rate of Rinskor applied, application volume, and adjuvant use for all parameters evaluated (Tables 1 and 2). Poor levels of control of all species were observed when no MSO was added. Barnyardgrass control 28 days after application was the greatest when Rinskor Active was applied at either 10 or 20 gal/acre of spray volume in conjunction with 48 fl oz/acre of MSO (Table 1). In contrast, low levels of barnyardgrass control were observed when Rinskor was applied at 5 gal/acre of spray volume and only contained 0 or 16 fl oz/acre of MSO. A similar trend was also observed for yellow nutsedge (Table 2).

Hemp sesbania in general exhibited high levels of sensitivity to applications of Rinskor, but control tended to improve as spray volume and MSO increased (Table 1). Similar to hemp sesbania, Palmer amaranth, a problematic weed on rice levees, displayed sensitivity to applications of Rinskor and control tended to improve as spray volume and MSO increased. Behavior of all weeds species evaluated in this trial may have been attributed to the dryland environment in which they were subjected and higher levels of control should occur in a flooded environment typical of mid-South rice culture. Even so, all species exhibited a high level of sensitivity to Rinskor especially in situations where the application parameters were conducive, thereby indicating the potential for this new herbicide to control problematic weeds in rice.

SIGNIFICANCE OF FINDINGS

The significance of this research is primarily for the optimization of Loyant herbicide containing Rinskor Active on problematic weeds in mid-South rice. Increasing rates of MSO tend to improve overall weed control, and excellent coverage was achieved with spray volumes of 10 gal/acre. Higher spray volumes (e.g., 20 gal/acre) may be needed in areas with dense weed populations. Loyant herbicide with Rinskor Active will provide mid-South rice growers with an alternative herbicide mode of action that is capable of achieving a high level of weed control.

ACKNOWLEDGMENTS

The support for this research provided by Dow AgroSciences, the Arkansas Rice Research and Promotion Board, and the University of Arkansas System Division of Agriculture is appreciated.

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Table 1. Influence of herbicide rate, application volume, and adjuvant use on barnyardgrass and hemp sesbania control 28 days after application of Rinskor™ Active.

			Control	
Herbicide rate	**Application volume**	**MSO† rate**	**Barnyardgrass**	**Hemp sesbania**
(lb ai/acre)	**(gal/acre)**	**(fl oz/acre)**	**(%)**	
0.015	5	0	0 j‡	0 m
		16	48 i	78 j
		32	49 i	80 i
		48	59 h	80 h
	10	0	0 j	10 l
		16	74 f	85 e
		32	84 e	85 e
		48	84 e	90 d
	20	0	0 j	10 l
		16	89 d	95 b
		32	95 bc	95 b
		48	95 bc	97 a
0.030	5	0	0 j	10 l
		16	69 g	84 d
		32	74 f	85 d
		48	84 e	89 c
	10	0	0 j	11 l
		16	81 e	89 c
		32	93 c	93 b
		48	97 ab	99 a
	20	0	0 j	17 k
		16	94 bc	98 a
		32	95 bc	99 a
		48	99 a	99 a

† MSO = methylated seed oil.

‡ Means followed by the same letter are not statistically different according to Fisher's protected least significant difference test (P = 0.05).

Table 2. Influence of herbicide rate, application volume, and adjuvant use on yellow nutsedge and Palmer amaranth control 28 days after application of Rinskor™ Active.

			Control	
Herbicide rate	**Application volume**	**MSO† rate**	**Yellow nutsedge**	**Palmer amaranth**
(lb ai/acre)	**(gal/acre)**	**(fl oz/acre)**	**(%)**	
0.015	5	0	0 j‡	0 l
		16	41 i	49 h
		32	44 i	69 g
		48	44 i	74 f
	10	0	0 j	4 l
		16	64 h	84 e
		32	74 f	89 c
		48	84 f	94 b
	20	0	0 j	9 k
		16	89 g	94 d
		32	95 ab	97 c
		48	97 ab	97 b
0.030	5	0	0 j	5 l
		16	61 e	79 b
		32	74 c	89 b
		48	95 ab	94 a
	10	0	0 j	0 j
		16	84 b	94 b
		32	93 bc	94 a
		48	97 ab	98 a
	20	0	0 j	14 i
		16	97 ab	94 b
		32	99 a	97 a
		48	99 a	99 a

† MSO = methylated seed oil.

‡ Means followed by the same letter are not statistically different according to Fisher's protected least significant difference test (P = 0.05).

Evaluation of Topramezone (Armezon®/Impact®) for Rice Weed Control

R.C. Scott[1], J.K. Norsworthy[2], J.C. Moore[1], and B.M. Davis[1]

ABSTRACT

A field trial was conducted in the late summer of 2015 to evaluate weed control and rice tolerance to topramezone (Armezon®/Impact®) herbicide. Armezon 2.8 L was used as the source of topramezone. Treatments included Armezon applied alone at 0.25, 0.50, 0.75, and 1.0 fl oz/acre or at 0.50 fl oz/acre in combination with 32 fl oz/acre of Facet® L, 20 fl oz/acre of RiceStar® HT, or 0.67 oz/acre of Permit Plus®. Armezon applied at the 3- to 4-lf rice stage resulted in 30% crop injury or more at 14 days after treatment (DAT) when applied alone at 1.0 fl oz/acre or at 0.5 fl oz/acre in combination with RiceStar® HT. All other rates and combinations resulted in 15% injury or less. Armezon alone at 0.5 fl oz/acre injured rice only 3% at 14 DAT. Armezon applied alone at 0.5 fl oz/acre or higher resulted in over 90% control of barnyardgrass, Amazon sprangletop, and hemp sesbania when evaluated at 28 DAT. No antagonism was observed between Armezon and its tank-mix partners.

INTRODUCTION

Approximately 50% of the rice grown in Arkansas is Cleafield rice and receives applications of the herbicides Newpath® (imazethapyr) or Beyond® (imazamox) (Wilson et al., 2010). The other 50% of rice grown in the state lacks the Clearfield tolerance trait and is grown using conventional rice herbicide chemistries. Over the years, repeated use of the same herbicides has resulted in the development of resistant barnyardgrass biotypes to propanil (Weed Science Society of America; WSSA Group 7), the acetolactate synthase (ALS) chemistry (WSSA Group 2) such as Newpath and Regiment®, and Facet® (WSSA Group 4) herbicides (Carey et al., 1995; Norsworthy et al., 2013a, b; Wilson et al., 2014). Hence, there has been a heavy reliance on Group 1 and Group 13 herbicide chemistries such as RiceStar® HT and Command®, respectively. Resistance to these chemistries, while not currently widespread, has been documented in species including barnyardgrass and Amazon sprangletop (Norsworthy et al., 2013a,b). Although

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some new herbicide chemistries for rice are being developed, many are in the same basic herbicide classes or do not effectively control all resistant weeds. Therefore, any new herbicide mode of action for use in rice would be valuable in preventing further development of resistant weeds, especially barnyardgrass.

Topramezone is sold under the trade names Armezon® and Impact® for use in corn. It is a member of the HPPD class of herbicides (WSSA Group 27; WSSA Herbicide Handbook, 2014). It controls weeds by inhibition of the enzyme 4-hydroxyphenylpyruvate dioxygenase (4-HPPD) which effects carotenoid biosynthesis. This results in bleaching and chlorosis of susceptible plant leaves and ultimately death. Currently, there are no other herbicides labeled for use in rice from this family of chemistry, although at least one other is currently under development (Davis et al., 2014). However, that product (i.e., benzobicyclon) can only be applied post-flood, which will likely limit its potential for widespread use.

The objective of this research was to evaluate the potential of topramezone for weed control and crop tolerance in rice and assess the value of further study.

PROCEDURES

This experiment was conducted at the University of Arkansas System Division of Agriculture's Pine Bluff Research Farm located just north of Lonoke, Ark., in the summer of 2015. The soil texture is a silt loam with a pH of 6.3. Clearfield rice CL151 was planted on 5 August 2015 using a Hege plot drill calibrated to deliver a seeding rate of 90 lb/acre on 7.5-in. wide rows. Plot size was 5 ft × 25 feet. The study was conducted with a randomized complete block design having four replications.

Treatments consisted of topramezone as the formulated product Armezon (2.8 lb ai/gal) applied alone at 0.25, 0.50, 0.75, and 1.0 fl oz/acre or at 0.50 fl oz/acre in combination with 32 fl oz/acre of Facet L, 20 fl oz/acre of RiceStar HT, or 0.67 oz/acre of Permit Plus®. The treatments were applied early post-emergence when rice was at the 3- to 4-lf growth stage with a CO_2-backpack sprayer calibrated to deliver a spray solution at 10 gal/acre. Also at the time of application, barnyardgrass (2- to 3-lf), hemp sesbania (2- to 3-lf), and Amazon sprangletop (1- to 2-lf) were present. All treatments included 1% v/v crop oil concentrate. The rice was grown according to University of Arkansas System Division of Agriculture Cooperative Extension Service recommendations with the exception of a late planting date (17 August 2015); therefore, plots were not harvested.

Data collected included estimates of visible injury and control ratings for barnyardgrass, Amazon sprangletop, and hemp sesbania at 7, 14, and 28 days after treatment (DAT). Data were subjected to analysis of variance and Fisher's least significant difference test used for mean separation at $P = 0.05$ level of significance using ARM 9.1.4 (Gylling Data Management, Inc., Brookings, S.D.).

RESULTS AND DISCUSSION

Armezon applied at 0.25 to 0.50 fl oz/acre resulted in less than 5% crop injury at all times evaluated (Table 1). At 7 DAT, the 0.5 fl oz/acre rate of Armezon applied in

combination with RiceStar HT (20 fl oz/acre) injured rice 16%, 12 percentage points more than Armezon applied alone at the same rate. By 14 DAT, 1.0 fl oz/acre of Armezon alone and Armezon at 0.5 fl oz/acre plus RiceStar HT resulted in 30% and 36% injury, respectively. These data indicate a synergistic effect on rice injury between Armezon and RiceStar HT; however, the research needs to be repeated to confirm this observation.

Armezon at 0.75 fl oz/acre injured rice 15% at 14 DAT. By 28 DAT, only Armezon plus RiceStar HT cause rice injury greater than 12% (Table 1). Based on these data, the rice variety evaluated does express tolerance to near "labeled" rates of Armezon for corn. Further studies are needed to look at multiple varieties and include at least one additional rate (0.625 fl oz/acre) of Armezon to fully evaluate rice tolerance.

Armezon applied alone at 0.5 fl oz/acre or more and in the various tank-mixtures provided at least 90% control of barnyardgrass, hemp sesbania, and Amazon sprangletop at 28 DAT (Table 1). The addition of Facet L, RiceStar HT, or Permit Plus did not improve weed control at 28 DAT. However, at 14 DAT, the addition of Facet L increased hemp sesbania control to 100%. No antagonism was observed from the three tank-mix partners evaluated. These treatments should be repeated and future research should include: Command, propanil, Provisia, Newpath, Rinskor Active, and Clincher to aid in further understanding the fit of Armezon in various rice weed control programs.

SIGNIFICANCE OF FINDINGS

The results of this exploratory study indicate that it may be possible to refine the rate and timing of application of topramezone to fit a drill-seeded rice production system in Arkansas. Good control of barnyardgrass was observed which could mean a new mode of action for control of resistant biotypes of this weed in rice. This could have a significant impact on the on-going development of resistant barnyardgrass in Arkansas. Over the next 2 years, we will take an in-depth look at the use of topramezone in rice and hopefully have a product that warrants labeling in mid-South rice.

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Table 1. Rice injury at 7, 14, and 28 days after treatment (DAT) and barnyardgrass, Amazon sprangletop, and hemp sesbania control at 14 and 28 DAT.

Treatment	Herbicide rate	Visible injury			Barnyardgrass		Hemp sesbania		Amazon sprangletop	
		7 DAT	14 DAT	28 DAT	14 DAT	28 DAT	14 DAT	28 DAT	14 DAT	28 DAT
	(oz/acre)	(%)								
Armezon®	0.25	0	3	0	63	68	88	60	70	82
Armezon	0.50	4	3	1	79	93	88	96	87	92
Armezon	0.75	7	15	1	83	94	99	98	88	96
Armezon	1.0	9	30	12	88	95	96	99	90	98
Armezon +	0.5									
Facet® L	32	3	2	0	90	98	100	100	90	100
Armezon +	0.5									
RiceStar® HT	20	16	36	19	90	99	100	100	95	98
Armezon +	0.5									
Permit Plus®	0.67	0	2	0	90	94	91	99	88	96
$LSD_{0.05}$		2	4	5	12	7	7	6	4	4

Rice Flatsedge Resistance to Acetolactate Synthase-Inhibiting Herbicides

P. Tehranchian[1], J.K. Norsworthy[1], R.C. Scott[2], and L.T. Barber[2]

ABSTRACT

Rice flatsedge is a persistent weed in rice crops in the mid-southern United States. In 2010, halosulfuron (Permit®) was reported to be non-effective on a rice flatsedge biotype in an eastern Arkansas rice field. The biotype was later confirmed resistant to the labeled field rate of halosulfuron (0.047 lb ai/acre) in the greenhouse herbicide screening program. The resistant biotype was not controlled at the highest halosulfuron dose (3.0 lb ai/acre) tested in a dose-response study. Based on the resistance index (R/S) ratio calculated from the lethal dose required for 50% plant mortality (LD_{50}), the resistant biotype was > 483-fold less responsive to halosulfuron compared to a susceptible biotype. The resistant biotype was also cross resistant to other acetolactate synthase (ALS)-inhibiting herbicides [bispyribac-sodium (Regiment®), imazamox (Beyond®), imazethapyr (Newpath®), and penoxulam (Grasp®)] from four different chemical families. Control of the resistant and susceptible biotypes was ≥ 93% using 2,4-D (Weedar® 64), bentazon (Basagran®), and propanil (SuperWham®) at the labeled field rate. Based on this research, a high level of resistance to halosulfuron has evolved in a biotype of rice flatsedge in Arkansas; fortunately, alternative herbicides are available that provide effective control.

INTRODUCTION

Rice flatsedge (*Cyperus iria*) is considered one of the predominant annual monocot weeds in dry-seeded rice production systems in Arkansas (Norsworthy et al., 2013). Over the past 10 years in the mid-southern U.S., ALS-inhibiting herbicides have been the most popular class of herbicides used for post-emergence (POST) weed control including sedge species in imidazolinone (IMI)-resistant rice production. Effective control of herbicide-resistant (e.g. propanil, quinclorac, and clomazone) barnyardgrass (*Echinochloa crus-galli*) biotypes using ALS-inhibiting herbicides has been achieved along with control of rice flatsedge in IMI-resistant rice (Levy et al., 2006; Webster et

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al., 2012). However, overuse of the ALS-inhibiting herbicides for weed control and lack of integrated weed management strategies has caused selection for resistance in several weed species common in rice (Heap, 2015).

In 2010, halosulfuron at the labeled field rate failed to control a rice flatsedge biotype in a rice field in eastern Arkansas. Resistance of the rice flatsedge biotype to the labeled field rate of halosulfuron was confirmed in preliminary greenhouse studies. The objectives of this research were to: 1) determine the magnitude of halosulfuron resistance in a rice flatsedge biotype in Arkansas, 2) characterize cross-resistance to other ALS-inhibiting herbicides from four different chemical families, and 3) evaluate alternative herbicides available in Arkansas rice/soybean systems for control of the resistant biotype.

PROCEDURES

Greenhouse experiments were conducted at the University of Arkansas System Division of Agriculture's Altheimer Laboratory located in Fayetteville, Ark. Seeds of the resistant biotype (*Res*) were collected from the infested field and seeds of a halosulfuron-susceptible biotype (*Sus*) were provided from a seed repository in Davis, Calif. Seed of all biotypes were planted individually in plastic flats and seedlings were transplanted at the 2-lf stage into plastic pots (4 in. diameter × 6 in. height). Plants were maintained in the greenhouse under 86 °F/68 °F ± 3 °F day/night temperature and a 14-h photoperiod provided by high pressure sodium lights. All herbicide treatments were applied to 3- to 4-lf rice flatsedge plants using a research spray chamber equipped with a boom mounted with 800067 flat-fan tips (Teejet® Technologies, Springfield, Ill.) calibrated to deliver 20 gal/acre of herbicide solution at 40 PSI.

The dose-response experiment was conducted in a randomized complete block design (RCBD). There were 20 seedlings of each biotype treated with 6 doses of halosulfuron. The herbicide doses for the *Sus* biotype were 0.0625, 0.125, 0.25, 0.5, 1, and 2× the labeled field rate of halosulfuron, whereas the *Res* biotype was treated with 1, 2, 4, 8, 16, and 32× the labeled field rate. All herbicide solutions contained 1% v/v crop oil concentrate, 0.25% v/v nonionic surfactant, or 0.75% v/v Dyne-A-Pak. Mortality data were recorded at 28 days after treatment (DAT), and data were subjected to probit analysis using PROC PROBIT in SAS V. 9.3 (SAS Institute, Inc., Cary, N.C.).

The herbicide evaluation studies were conducted in a factorial RCBD with five ALS-inhibiting herbicides from four different chemical families and five non-ALS-inhibiting herbicides currently labeled in Arkansas rice/soybean rotations (Table 1). Each treatment was replicated four times, and the experiment was repeated. Herbicide treatments were conducted as mentioned in the dose-response study. Adjuvants were added as shown in Table 1. At 28 DAT, visual assessments of plant response to each herbicide treatment were taken on a scale of 0 (no injury) to 100 (plant death). Data were subjected to analysis of variation (ANOVA) using PROC MIXED in SAS (SAS Institute, Inc., Cary, N.C.). Means were separated using Fisher's protected least significant difference test at $P = 0.05$.

RESULTS AND DISCUSSION

Greenhouse Dose-Response Experiment

Even the highest dose of halosulfuron (3.0 lb ai/acre) did not kill 50% of the *Res* biotype plants. Based on LD_{50} values, the *Res* biotype was > 438-fold less sensitive to halosulfuron in comparison to the *Sus* biotype. The occurrence of such a high level of resistance usually corresponds to an altered target site. A high level of resistance to this chemistry has been confirmed in other sedge species in Arkansas rice such as yellow nutsedge (*Cyperus esculentus*) and smallflower umbrellasedge (*Cyperus difformis*; Tehranchian et al., 2014; 2015).

Cross and Multiple Resistance

Control of the *Res* biotype was ≤6% with the labeled rate of imazethapyr, imazamox, halosulfuron, bispyribac-sodium, and penoxulam (Fig. 1). This confirmed that the *Res* biotype was cross-resistant to ALS-inhibiting herbicides from four chemical families (imidazolinone, pyrimidinyl benzoate, sulfonylurea, and triazolopyrimidine). On the contrary, all ALS-inhibiting herbicides tested in this experiment effectively (≥98%) controlled the *Sus* biotype. Cross-resistance to ALS-inhibiting herbicides has been reported in other sedge species. For example, smallflower umbrellasedge in California has also evolved cross-resistance to five ALS-inhibiting herbicide families (Merotto et al., 2009). Cross-resistance to herbicides in crop weeds can be due to altered target protein structure or enhanced metabolic capacity to detoxify the herbicides (Preston and Mallory-Smith, 2001; Yu et al., 2013; Yu and Powles, 2014). A labeled field rate of 2,4-D, bentazon, and propanil effectively controlled (≥93%) both rice flatsedge biotypes (Fig. 2). In contrast, thiobencarb and quinclorac resulted in ≤52% control of the *Res* and *Sus* biotypes.

SIGNIFICANCE OF FINDINGS

A rice flasedge biotype has evolved cross-resistance to ALS-inhibiting herbicides from four different chemical families in Arkansas rice. Application of non-ALS-inhibiting herbicides currently labeled in Arkansas rice can be used to effectively control the resistant rice flatsedge biotype. Even with propanil-resistant barnyardgrass being common in Arkansas rice, prudent use of propanil can decrease selection pressure for the evolution of ALS-inhibiting herbicide resistance in rice flatsedge. Integrated weed management strategies must be employed if the use of herbicides for controlling this weed is to be sustained. Further research needs to be conducted to fully understand the resistance mechanism(s) within this biotype.

ACKNOWLEDGMENTS

The authors are thankful to the Arkansas Rice Research and Promotion Board and the University of Arkansas System Division of Agriculture for funding and supporting this research.

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Table 1. Acetolactate synthase (ALS)-inhibiting and alternative herbicides available in Arkansas rice/soybean rotations used in this study.

Common name	Trade name	Labeled field rate	Adjuvant
		(lb ai/acre)	(% v/v)
ALS-inhibiting herbicides			
Imazamox	Beyond®	0.047	1% COC[a]
Imazethapyr	Newpath®	0.095	0.25% NIS[b]
Bispyribac-sodium	Regiment®	0.032	0.75% Dyne[c]
Penoxsulam	Grasp®	0.031	1% COC
Halosulfuron	Permit®	0.047	1% COC
Alternative rice herbicides			
2,4-D	Weedar 64®	1.0	0.25% NIS
Bentazon	Basagran®	1.0	---
Propanil	SuperWham®	4.0	---
Quinclorac	Facet® L	0.5	---
Thiobencarb	Bolero®	4.0	---

[a] COC = crop oil concentrate.
[b] NIS = nonionic surfactant.
[c] Dyne-A-Pak.

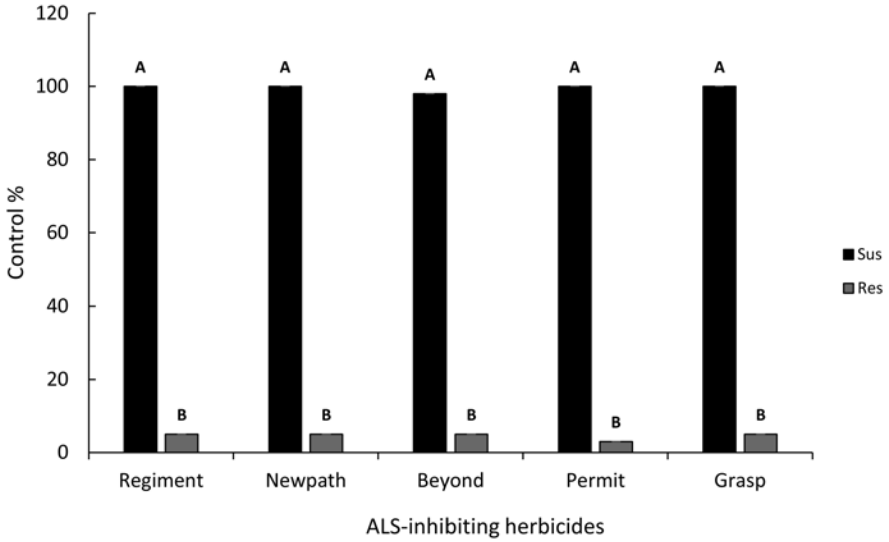

Fig. 1. Effectiveness of acetolactate synthase ALS-inhibiting herbicides [bispyribac-sodium (Regiment®), imazethapyr (Newpath®), imazamox (Beyond®), halosulfuron (Permit®), and penoxulam (Grasp®) for controlling rice flatsedge biotypes (*Res* and *Sus*) at 28 days after treatment. *Sus* = susceptible; *Res* = Resistant.

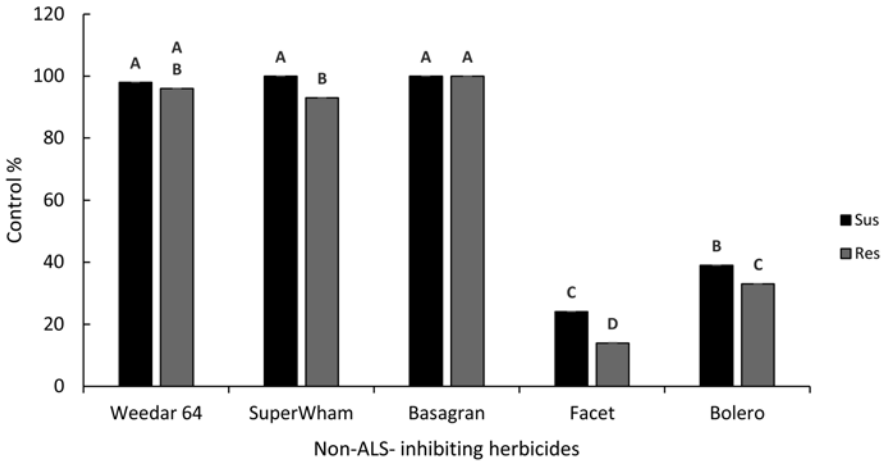

Fig. 2. Effectiveness of non-acetolactate synthase (ALS)-inhibiting herbicides 2,4-D (Weedar® 64), bentazon (Basagran®), propanil (SuperWham®), quinclorac (Facet® L), and thiobencarb (Bolero®)] labeled in Arkansas rice for controlling rice flatsedge biotypes (*Res* and *Sus*) at 28 days after treatment. *Sus* = susceptible; *Res* = Resistant.

Evaluation of a Benzobicyclon Plus Halosulfuron Premix for Weed Control in Arkansas Rice

M.L. Young[1], J.K. Norsworthy[1], C.A. Sandoski[2], R.C. Scott[3], and L.T. Barber[3]

ABSTRACT

Rogue®, a new rice herbicide, is being developed by Gowan Company for postflood control of problematic weeds. Rogue Plus®, a premix, will contain a mixture of halosulfuron (Group 2) and benzobicyclon (Group 27) herbicides and will control a broad-spectrum of grasses, aquatics, broadleaves, and sedges, including those currently resistant to Group 2 herbicides. If labeled as expected, this will be the first 4-hydroxyphenylpyruvate dioxygenase (HPPD) herbicide commercially available in U.S. rice production. This new mode of action in rice will enable producers to control a variety of weed species that become increasingly more problematic as the season progresses. Field studies were conducted in 2014 and 2015 at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center near Stuttgart, Ark., to understand if the addition of halosulfuron (Permit®) to benzobicyclon would increase the level of weed control compared with benzobicyclon alone for barnyardgrass, Amazon sprangletop, ducksalad, California arrowhead, hemp sesbania, northern jointvetch, yellow nutsedge, and smallflower umbrellasedge. Treatments in 2014 included: benzobicyclon at 0.22 and 0.33 lb ai/acre, and a mixture of both rates of benzobicyclon plus halosulfuron at 0.03 and 0.05 lb ai/acre, and a control. In 2015, there were two additional treatments added to the treatment structure of halosulfuron at 0.03 and 0.05 lb ai/acre applied alone for a total of seven experimental treatments. Benzobicyclon alone was effective in controlling Amazon sprangletop, ducksalad, California arrowhead, and smallflower umbrellasedge. The addition of halosulfuron to benzobicyclon generally improved control of those weeds that were marginally controlled by benzobicyclon alone. The low rate combination of benzobicyclon plus halosulfuron was often as effective as the high rate of benzobicyclon alone. The results of this study suggest that benzobicyclon premixed with halosulfuron has potential for control of problematic weeds in Arkansas rice and could be used as an additional weed management tool for control of herbicide-resistant weeds.

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INTRODUCTION

Due to the repetitive use of the same herbicide modes of action in rice, many weeds have evolved herbicide resistance across the mid-South (Carey et al., 1995; Norsworthy et al., 2013a,b; Wilson et al., 2014). A new mode of action is needed in rice production with the increasing stress on our current herbicide chemistries. Gowan Company is developing benzobicyclon, a new herbicide for post-flood applications in rice. Benzobicyclon, a Group 27 herbicide, will represent a new option for rice producers that has activity against resistant weeds including barnyardgrass, ducksalad, and sedges (Heap, 2015). In particular, acetolactate synthase (ALS)-resistant barnyardgrass and sedges pose a significant threat to Arkansas rice production (Riar et al., 2012; Bagavathiannan et al., 2014).

Gowan Company also produces halosulfuron or Permit® 75DF, which is a Group 2 herbicide labeled in rice and several other crops for the control of annual broadleaf weeds and sedges. McCallister et al. (2009) documented that halosulfuron is most effective when combined with other herbicides especially for the control of broadleaf weeds. The increasing amount of herbicide-resistant species makes it important to mix multiple modes of action; therefore, the combination of halosulfuron plus benzobicyclon may provide a broader spectrum of weed control over the herbicides applied individually.

The objective of this research was to evaluate a premix of benzobicyclon and halosulfuron for its potential as a rice herbicide in mid-South rice production.

PROCEDURES

A study was initiated in the summer of 2014 and repeated in 2015 at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center near Stuttgart, Ark., to determine if the addition of halosulfuron (Permit) to benzobicyclon would increase the level or spectrum of weed control compared to benzobicyclon alone. Clearfield 111 rice was drill-seeded into a silt loam soil. The design was a randomized complete block with three replications. Bays were 150 ft × 10 ft wide and the plots planted into the bays were 75 ft × 6 ft with levees separating bays. Weeds across the entire test site were initially suppressed with a 0.5× labeled rate of clomazone at planting followed by a 0.5× labeled rate of imazethapyr at 2 weeks after rice emergence. Treatments in 2014 included: benzobicyclon at 0.22 and 0.33 lb ai/acre, a mixture of both rates of benzobicyclon plus halosulfuron at 0.03 and 0.05 lb ai/acre, and a control. In 2015, there were two additional herbicide treatments added to the treatment structure, which included halosulfuron at 0.03 and 0.05 lb ai/acre applied alone for a total of seven experimental treatments. All treatments were applied 1 week after the permanent flood was established. All applications were made using a CO_2-pressurized backpack sprayer calibrated to deliver 15 gal/acre. Visual weed control ratings were taken every 2 weeks and were estimated using a scale of 0% to 100%, where 0 is no control and 100 is complete control. Rough-rice yield data were collected upon maturity of the crop. All data were subjected to analysis of variance using JMP® Pro 12.1.0 (SAS Institute

Inc. Cary, N.C.), and means were separated using Fisher's protected least significant difference test ($P = 0.05$).

RESULTS AND DISCUSSION

In 2014, as late as 7 weeks after treatment (WAT), significant differences were detected between treatments for the control of northern jointvetch. Where benzobicyclon was applied alone, both treatments exhibited significantly lower levels of control compared to when benzobicyclon was combined with halosulfuron (Fig. 1). By 8 WAT, both rates of benzobicyclon applied alone or in mixture with halosulfuron provided complete control of rice flatsedge, yellow nutsedge, and Amazon sprangletop (data not shown).

In 2015, similar results to those in 2014 were seen with the addition of halosulfuron to benzobicyclon. The addition of halosulfuron to benzobicyclon did not improve barnyardgrass control over benzobicyclon alone (Fig. 2). Benzobicyclon plus halosulfuron at the high rate provided 81% control of barnyardgrass. It does not appear that the herbicide combination of halosulfuron plus benzobicyclon will provide a level of control deemed effective by most growers. By 9 WAT, all treatments containing benzobicyclon provided complete control of ducksalad, California arrowhead, and ALS-resistant smallflower umbrellasedge (Fig. 3).

Rough rice yields were collected both years; however, no significant differences were detected among treatments (data not shown).

SIGNIFICANCE OF FINDINGS

Rogue Plus®, the likely tradename of the premix of benzobicyclon plus halosulfuron, will provide Arkansas rice growers suppression of barnyardgrass and effective control of Amazon sprangletop, northern jointvetch, hemp sesbania, ducksalad, California arrowhead, yellow nutsedge (resistant and susceptible biotypes), rice flatsedge (resistant and susceptible biotypes), and smallflower umbrellasedge (resistant and susceptible biotypes). Additionally, the benzobicyclon plus halosulfuron combination brings an additional herbicide mode of action to Arkansas rice for broad-spectrum, postflood management of many of the most common and problematic weeds. It will also aid in the fight against resistant weeds, especially sedges like yellow nutsedge, rice flatsedge, and smallflower umbrellasedge.

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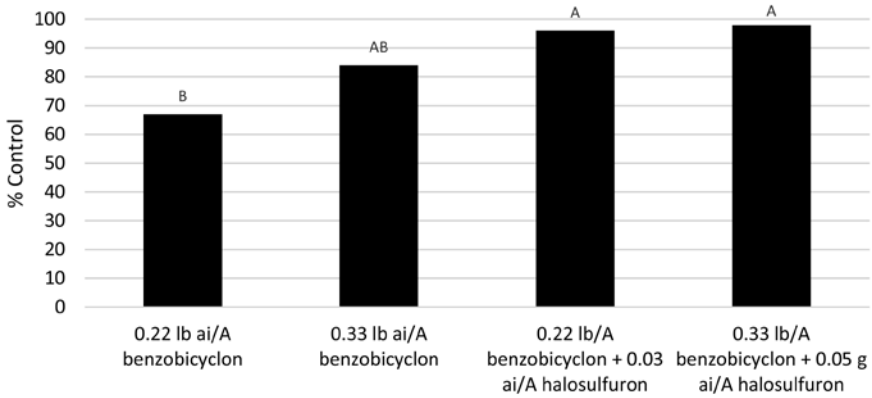

Fig. 1. Control of northern jointvetch 7 weeks after treatment in 2014. Means having the same letter are not significantly different according to Fisher's protected least significant difference test at *P* = 0.05.

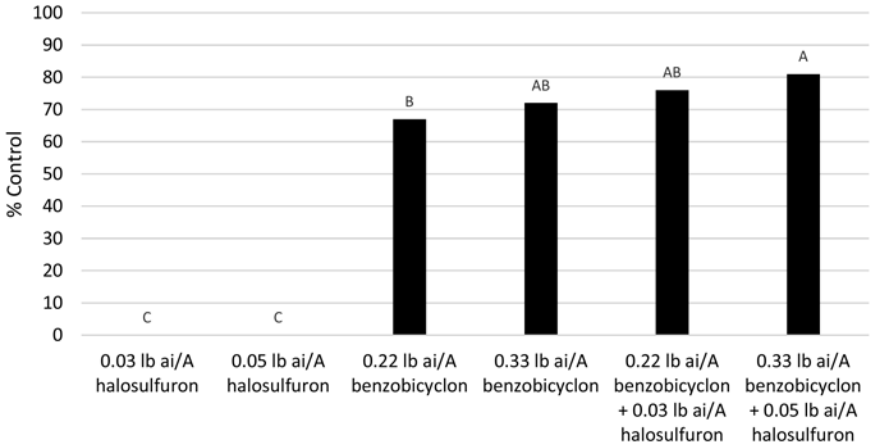

Fig. 2. Barnyardgrass control 9 weeks after treatment in 2015. Means having the same letter are not significantly different according to Fisher's protected least significant difference test at *P* = 0.05.

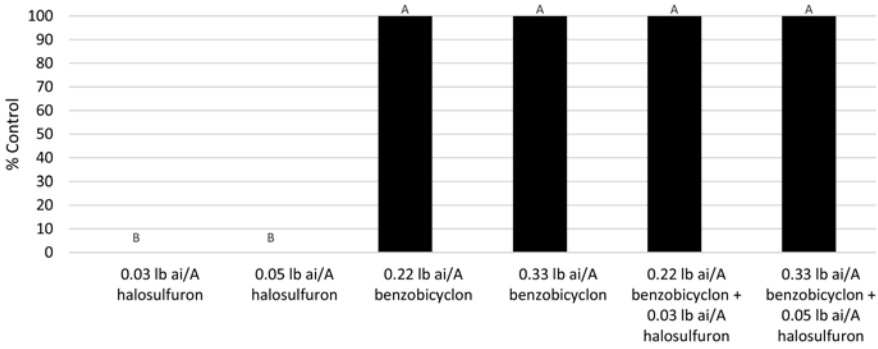

Fig. 3. California arrowhead, ducksalad, and acetolactate synthase (ALS)-resistant smallflower umbrellasedge control 9 weeks after treatment in 2015. Means having the same letter are not significantly different according to Fisher's protected least significant difference test at *P* = 0.05.

2015 Degree Day 50 Thermal Unit Thresholds for New Rice Cultivars and Seeding Date Studies

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ABSTRACT

The Degree-Day 50 (DD50) computer program has been one of the most successful management aids developed by the University of Arkansas System Division of Agriculture. The program predicts critical growth stages that assist in optimizing crop management operations. In order to be effective, the computer program must be updated continually as new rice cultivars become available. To fulfill 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 2015 season, plant developmental data, DD50 thermal unit accumulation, and grain and milling yield performance data for nineteen cultivars were evaluated over five seeding dates under the dry-seeded, delayed-flood management system that is commonly used in southern U.S. rice production.

INTRODUCTION

Developed in the 1970s to help farmers time midseason nitrogen (N) applications with precision, the Degree-Day 50 (DD50) computer program currently provides predicted dates for timing twenty-six key management decisions including fertilization, pesticide applications, permanent flood establishment, times for scouting insect and disease, predicted draining date, and suggested harvest time.

The DD50 is a modification of the degree-day growing concept with daily high and low air temperatures used to quantify a day's thermal accumulations for plant growth. The DD50 Program generates a predicted rice plant development file that is cultivar-specific based on the accumulation of DD50 units beginning at emergence. The file is

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created by calculating thermal unit accumulation using 30-year average weather data collected by the National Weather Service weather stations closest to a rice producer's location in Arkansas. As the season progresses the program is updated with the current year's weather data.

The data used to predict plant development for a specific cultivar is obtained in yearly studies where promising experimental lines and newly released conventional and hybrid rice cultivars are evaluated in four to six seeding dates per season within the recommended range of rice seeding dates 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 stages and dates when particular management practices could be performed. Therefore, the objectives of this study were to develop a DD50 thermal unit accumulation database for promising new cultivars, to verify and refine the existing database of current cultivars, and to assess the effect of seeding date on DD50 thermal unit accumulation. Also, determining the effects of seeding date on grain and milling yields helps determine optimal seeding dates for a particular cultivar.

PROCEDURES

The 2015 DD50 study was conducted at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC) near Stuttgart, Ark., on a DeWitt silt loam soil. Fifteen pure-line cultivars (i.e., CL111, CL151, CL153, CL163, CL172, CL271, CL272, Diamond, Jupiter, LaKast, Mermentau, Roy J, Titan, Wells, and the experimental line MSX4077) were dry-seeded at a rate of 30 seed/ft^2 in plots 9 rows wide (7-inch spacing) and 15 ft long. Four hybrids (i.e., CLXL729, CLXL745, XL753, and XL760) were seeded into plots of the same dimensions using a reduced seeding rate for hybrids of 13 seed/ft^2. The seeding dates for 2015 were 3 April, 21 April, 5 May, 19 May, 3 June, and 16 June. However, the 16 June seeding date was lost due to bird depredation. General agronomic information is shown in Table 1. Established cultural practices for dry-seeded, delayed-flood rice production were followed. A single preflood application of 120 lb N/acre as urea was applied to all plots at the 4- to 5-lf growth stage and flooded within 2 days of preflood N fertilization. The flood was maintained until maturity. The collected data for each of the seeding dates included: maximum and minimum daily temperatures, date of seedling emergence, and the number of days and DD50 units required to reach 50% heading. The number of days and DD50 thermal units required to reach 0.5-inch internode elongation (IE) was collected for the 3 April, 5 May, and 3 June seeding dates for selected cultivars. At maturity, the five center rows in each plot were harvested, weight of grain and moisture content were recorded, and a subsample of grain was taken for milling purposes. The grain yield was adjusted to 12% moisture and reported in bushels/acre (bu/acre). The dry rice was milled to obtain percent head rice (HR; whole kernels) and percent total white rice (TR, whole + broken kernels) to provide the ratio of %HR - %TR. The arrangement of each seeding date was a randomized complete block design with four

replications. Statistical analyses were conducted using PROC GLM (SAS version 9.4, SAS Institute, Inc., Cary, N.C.) and mean separation was conducted using Fisher's protected least significant difference test ($P = 0.05$) where appropriate.

RESULTS AND DISCUSSION

Time between seeding and emergence ranged from 6 to 15 days (Table 1). In general, seeding date (SD) studies report a decrease in days between seeding and emergence as the seeding date is delayed. The 2015 study followed this general trend of decreasing days from seeding to emergence as SD was delayed from early April to late June, except for the second SD (21 April) which increased by four days compared to the 3 April SD. The time from seeding to establishment of permanent flood followed a similar decreasing pattern as the SD was delayed; ranging from 47 days for the 3 April to 23 days for the 3 June seeding dates and slightly increased to 24 days for the mid-June SD. The times from emergence to flooding in 2015 had a general decreasing trend as SD was delayed also, with 47 days for the 3 April SD and then a 3 day decrease for each subsequent SD until the 19 May SD, a decrease of 8 days between the 19 May and 3 June seeding dates and an increase of 1 day as SD was delayed until 16 June.

The days required from emergence to 0.5-inch IE for the selected cultivars in the three seeding dates sampled, averaged 53 days (Table 2). A decreasing trend in time was observed to reach 0.5-inch IE as SD was delayed. Across cultivars, the average number of days to reach 0.5-inch IE ranged from 67 days when seeded in early April to 43 days when seeded in early June. Time required for vegetative growth averaged across seeding rates ranged between 48 days for CL153 to 57 days for Jupiter. The DD50 thermal unit accumulation for vegetative growth averaged across SD ranged from a low of 1215 for CL153 to a high of 1476 for Jupiter.

During 2015, the time needed from emergence to reach the developmental stage known as 50% heading averaged across SD and cultivars was 78 days (Table 3). The average time for cultivars to reach 50% heading ranged from 89 days when seeded in early April to 71 days when seeded in early June. For individual cultivars the time required to reach 50% heading ranged from 66 days for CLXL729 and CLXL745 when seeded in early June to 95 days for Jupiter when seeded in early April. The thermal unit accumulation from emergence to 50% heading averaged 2131 across SD and cultivars. The individual cultivar DD50 thermal unit accumulation from emergence to 50% heading ranged from a low of 1968 for CLXL745 seeded 3 April to a high of 2369 for Roy J seeded 19 May. The 19 May SD generally required the greatest number of DD50 units from emergence to 50% heading.

Average grain yield for the 2015 study across SD and cultivars was 174 bu/acre (Table 4). When averaged across cultivars, the 3 April SD had the highest grain yield and the 3 June SD had the lowest grain yield. Mean grain yields were numerically higher for the 3 April SD followed by similar yields for 5 May and 19 May. An uncharacteristic drop-off in grain yield was measured when the cultivars were seeded 21 April with similar reports of poor yields in production fields seeded during the same time. The

most consistent cultivars across SD were the hybrids XL760, XL753, and CLXL729 with grain yield averages of 221, 220, and 215 bu/acre, respectively. Pure-line cultivars performing well across SD were Diamond, Titan, and Roy J with grain yield averages of 192, 175, and 170 bu/acre, respectively.

During 2015, the milling yield (head rice, HD / total white rice, TR) averaged across SD and all cultivars was 63% head rice and 70% total white rice (Table 5). There was a noticeable trend for increased head rice and total white rice as SD was delayed. With a very few exceptions, all cultivars averaged 60% head rice yield or better during this study year regardless of SD.

SIGNIFICANCE OF FINDINGS

The data obtained during 2015 will be used to refine the DD50 thermal unit threshold for new pure-line cultivars and hybrids being grown. The grain and milling yield data will contribute to the database of information used by University personnel to help producers make decisions in regard to rice cultivar selection, in particular for early- and late-seeding situations.

ACKNOWLEDGMENTS

This research was funded and supported 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 the DD50 Program.

Table 1. General seeding, seedling emergence, and flooding date information for the DD50 seeding date study in 2015 at the Rice Research and Extension Center near Stuttgart, Ark.

	Seeding date					
	3 April	**21 April**	**5 May**	**19 May**	**3 June**	**16 June**
Emergence date	14 April	6 May	15 May	27 May	10 June	22 June
Flood date	28 May	4 June	13 June	26 June	8 July	24 July
Days from seeding to emergence	11	15	10	8	7	6
Days from seeding to flooding	47	44	36	31	23	24
Days from emergence to flooding	36	29	26	23	16	18

Table 2. Influence of seeding date on DD50 accumulations and days from emergence to 0.5-in. internode elongation of selected rice cultivars in studies conducted at the Rice Research and Extension Center, Stuttgart, Ark., during 2015.

	Seeding date							
	3 April		5 May		3 June		Average	
Cultivar	days	DD50[a] units	days	DD50 units	days	DD50 units	days	DD50 units
CL153	62	1322	46	1237	37	1085	48	1215
CL163	67	1478	52	1396	45	1331	55	1402
CL172	68	1509	51	1370	43	1259	54	1379
CL271	68	1508	54	1433	46	1379	56	1440
CL272	67	1488	53	1411	43	1275	54	1391
Jupiter	71	1594	54	1448	47	1387	57	1476
Diamond	67	1472	50	1331	42	1228	53	1343
LaKast	65	1418	49	1313	40	1180	51	1304
Titan	66	1441	51	1350	44	1307	53	1366
Wells	67	1486	50	1344	43	1259	53	1363
XL760	63	1351	47	1267	39	1157	50	1258
MSX4077	68	1516	54	1447	46	1355	56	1439
Mean	67	1465	51	1362	43	1267	53	1365
$LSD_{(0.05)}$[b]	1.9	55.6	1.5	39.8	1.8	58.1	NS	76.4

[a] DD50 units calculated daily by equation [(daily max temperature + daily min temperature)/2]-50.

[b] LSD = least significant difference.

Table 3. Influence of seeding date on DD50 accumulations and days from emergence to 50% heading of selected rice cultivars in studies conducted at the Rice Research and Extension Center, Stuttgart, Ark., during 2015.

	Seeding date											
	3 April		21 April		5 May		19 May		3 June		Average	
Cultivar	days	DD50[a] units	days	DD50 units	days	DD50 units	days	DD50 units	days	DD50 units	days	DD50 units
CL111	86	2032	76	2055	72	1994	72	2098	67	2029	75	2042
CL151	87	2047	77	2086	72	2010	73	2146	67	2036	75	2065
CL153	89	2116	79	2142	75	2098	74	2162	68	2051	77	2114
CL163	88	2095	82	2222	77	2153	76	2217	77	2291	80	2196
CL172	92	2193	82	2222	75	2098	74	2178	69	2081	78	2154
CL271	92	2194	81	2198	79	2215	77	2256	77	2291	81	2231
CL272	92	2220	80	2166	76	2114	76	2225	73	2190	79	2183
CLXL729	86	2026	76	2031	74	2058	72	2098	66	1998	75	2042
CLXL745	84	1968	74	1976	72	2002	70	2026	66	1998	73	1994
Diamond	89	2124	79	2126	75	2082	75	2194	73	2178	78	2141
Jupiter	95	2305	82	2238	78	2193	77	2272	74	2200	81	2241
LaKast	88	2098	76	2039	72	1994	73	2146	68	2058	75	2067
Mermentau	88	2089	79	2150	74	2066	73	2146	68	2051	76	2100
Roy J	92	2210	84	2309	79	2231	81	2369	77	2274	83	2278
Titan	86	2040	75	2023	72	2002	74	2154	68	2058	75	2055
Wells	91	2170	80	2158	75	2082	75	2209	72	2170	78	2158
XL753	85	2004	75	1999	72	1994	69	2002	67	2013	73	2002
XL760	89	2116	81	2198	78	2192	77	2256	71	2150	79	2182
MSX4077	91	2162	84	2301	78	2193	79	2315	77	2291	82	2252
Mean	89	2116	79	2139	75	2093	74	2182	71	2127	78	2131
$LSD_{(0.05)}$[b]	1.8	51.1	1.7	53.0	1.1	36.4	2.1	63.2	1.0	26.2	4.1	34.7

[a] DD50 units calculated daily by equation [(daily max temperature + daily min temperature)/2]-50.
[b] LSD = least significant difference.

Table 4. Influence of seeding date on grain yield of selected rice cultivars in studies conducted at the Rice Research and Extension Center, Stuttgart, Ark., during 2015.

	Grain yield by seeding date						
Cultivar	**3 April**	**21 April**	**5 May**	**19 May**	**3 June**	**16 June[a]**	**Average**
	(bu/acre)						
CL111	173	152	171	143	104	.	149
CL151	182	141	178	178	135	139	163
CL153	179	157	170	174	121	133	160
CL163	170	141	172	177	137	.	159
CL172	163	139	167	162	140	136	154
CL271	176	126	174	174	140	136	158
CL272	178	146	183	175	130	.	162
CLXL729	226	212	227	229	181	169	215
CLXL745	180	198	201	194	157	.	186
Diamond	211	164	192	209	185	181	192
Jupiter	183	157	165	161	161	151	165
LaKast	197	174	183	192	150	.	179
Mermentau	178	131	170	183	156	144	163
Roy J	193	142	165	180	169	160	170
Titan	222	178	178	149	148	.	175
Wells	159	139	170	179	146	.	159
XL753	225	227	232	225	191	202	220
XL760	233	212	224	235	204	191	221
MSX4077	189	141	171	167	140	.	162
Mean	221	162	184	184	152	158	174
$LSD_{(0.05)}$[b]	22.6	17.5	12.4	159	17.1	NA	13.4

[a] The 16 June seeding date not included in average due to bird damage at trial emergence. Values reported from plots with no bird damage only.

[b] LSD = least significant difference.

Table 5. Influence of seeding date on milling yield of selected rice cultivars in studies conducted at the Rice Research and Extension Center, Stuttgart, Ark., during 2015.

	Milling yield by seeding date					
Cultivar	**3 April**	**21 April**	**5 May**	**19 May**	**3 June**	**Average**
	---------- (%HR - %TR[a]) ----------					
CL111	62-69	65-71	65-71	65-70	67-72	65-70
CL151	62-69	67-70	66-71	67-71	67-72	66-71
CL153	63-68	66-69	66-70	66-70	66-71	65-70
CL163	57-65	63-69	63-69	64-69	65-69	62-68
CL172	64-69	66-70	65-70	66-70	66-71	65-70
CL271	63-68	63-69	64-70	63-71	69-71	64-70
CL272	62-68	63-70	59-70	60-70	67-70	62-69
CLXL729	56-66	56-68	61-69	65-71	66-71	61-69
CLXL745	57-68	55-69	60-71	63-71	65-72	60-70
Diamond	55-67	60-69	61-71	66-71	65-70	61-70
Jupiter	63-66	66-68	65-69	66-69	66-68	65-68
LaKast	53-67	54-68	58-69	65-71	65-72	59-70
Mermentau	62-68	66-69	66-70	65-69	67-71	65-69
Roy J	56-68	63-70	65-71	65-71	67-72	63-70
Titan	63-67	63-70	58-69	53-68	67-69	61-69
Wells	53-68	60-70	56-70	60-70	66-72	59-70
XL753	55-68	51-70	56-70	61-71	65-72	58-70
XL760	56-67	62-70	62-70	65-71	66-71	62-70
MSX4077	58-67	63-69	60-69	64-69	65-69	62-69
Mean	59-68	62-69	62-70	64-70	66-71	63-70
%HR $LSD_{(0.05)}$[b]	2.8	2.4	2.5	2.8	1.1	2.3
% TR $LSD_{(0.05)}$	1.0	1.1	0.8	1.1	0.9	0.9

[a] %HR - %TR = percent head rice - percent total white rice.
[b] LSD = least significant difference.

Continued Validation of the Nitrogen Soil Test for Rice on Clay Soils in Arkansas

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ABSTRACT

The development of the Nitrogen Soil Test for Rice (N-STaR) allows a site-specific nitrogen (N) recommendation for rice on silt loam soils in Arkansas. Expansion of the site-specific N test into clay soils and its use in 27 counties in Arkansas necessitated the validation of N-STaR for rice produced on clay soils. Davidson et al. (2014) initiated the validation of this new soil test, but stated that additional data should be collected to substantiate the findings. Therefore, seven additional sites across Arkansas were selected in 2015 for their wide difference in native soil-N and seeded to one of three rice cultivars. Stands were monitored for disease and pest pressure and yields were measured at the end of the season. Soil samples were taken at a 12-in. depth, analyzed using the N-STaR method, and the site-specific N rates were predicted using the calibration curves for 95% and 100% relative grain yield (RGY). In the validation trial, six treatments were compared: a control (0 lb N/acre); the N-STaR 95% and 100% RGY N rates applied in a standard two-way split (2-WS) application with 45 lb N/acre applied at beginning internode elongation and the remainder preflood; the N-STaR 95% and 100% RGY N rates applied in a single preflood (SPF) application; and the standard N recommendation based on cultivar, soil texture, and previous crop. Nitrogen rates predicted using N-STaR ranged from 0 lb N/acre to 180 lb N/acre. Rice yields obtained with the 95% RGY recommendation were statistically similar or greater than the standard N-rate recommendation for six of the seven sites while reducing the N rate between 50 to 200 lb N/acre compared to the standard N recommendation. Similarly, six of the seven 100% RGY recommendation trials were equal to or greater than the standard N recommendation. Overall, N-STaR is able to predict site-specific N fertilizer rates for rice produced on clay soils over a wide range of environmental and production settings.

INTRODUCTION

Rice is a major crop in eastern Arkansas, particularly around the Arkansas Grand Prairie and Mississippi Delta regions. In order to achieve optimum rice yields, N fertiliza-

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tion is required at 150 lb N/acre for most cultivars and is adjusted based on soil texture, rice cultivar, and previous crop. While rice has one of the highest N use efficiencies when managed correctly (Norman et al., 1992), fields with high levels of native-N may not respond or have little response to N fertilization which leads to poor N use efficiency. The excess N fertilizer at these locations increases the likelihood of N losses into the environment, and is an unnecessary expense for rice producers. Since the development of the Illinois Soil Nitrogen Test (ISNT) by Mulvaney and Khan in 2001, interest has reawakened for a N soil test that measures potentially mineralizable-N. The development of N-STaR by Roberts et al. in 2011 enabled a site-specific N recommendation for rice producers in Arkansas rather than the standard approach based on cultivar, soil texture, and previous crop. Site-specific N recommendations take into account the native-N of a soil and identify the sites where a decreased or increased rate of N, compared to the standard approach, is needed for optimal rice production. Soils separated by textural class—clays vs. silt loams and sands—yielded the strongest correlation between alkaline hydrolyzable-N and N rate required for optimum yield. In addition, Fulford et al. (2012) found the greatest predictability for clay soils to be a soil sample at the 0- to 12-in. depth. During the development of N-STaR for silt loam soils, the N-STaR calibration curves for the 95% and 100% relative grain yield (RGY) were validated to ensure predictability and to aid in the implementation of the N soil test (Roberts et al., 2013). The validation of N-STaR 95% and 100% calibration curves on clay soils in Arkansas was initiated by Davidson et al. in 2014 and this study is a continuation of that research. Davidson et al. (2014) found that the N-STaR recommendations accurately predicted the N needs of rice with the exception of the N-STaR 95% single preflood (SPF) N recommendation which may need to be adjusted. The purpose of this research is to increase the number of site-years in order to further evaluate the N-STaR N-rate recommendations under a two-way split (2-WS) and SPF application. The N-STaR method has the potential to decrease N loss into the environment and reduce the cost of fertilizer inputs for farmers (Williamson et al., 2013). The validation of N-STaR for clay soil will speed the adoption of this site-specific N soil test throughout Arkansas.

METHODS AND MATERIALS

In 2015, seven field experiments were conducted across producer's fields (4 sites) and at the University of Arkansas System Division of Agriculture experiment stations (3 sites) in Arkansas. Clay soil locations were chosen to ensure a wide range of native soil-N availability across sites. The plots were 9 rows wide (7-in. spacing) and 15 ft in length, and arranged in a randomized complete block design. Rice was dry-seeded (100 lb seed/acre on station) and grown to the 3- to 5-lf stage before a permanent flood was established (2- to 4-in. depth) and maintained until physiological maturity. Plots were monitored for pest pressure throughout the season. Four soil samples were taken at each location from the 0- to 12-in. depth, analyzed using N-STaR as outlined by Roberts et al. (2009), and the average N-STaR soil test value was used to produce the 95% or 100% RGY N-rate recommendations for each location. Six treatments were conducted

at each location: a control (0 lb N/acre); N-STaR 95% and 100% RGY applications; N-STaR 95% and 100% RGY SPF applications; and the standard N recommendation. For the standard N recommendation and the N-STaR 95% and 100% RGY applications, a 2-WS of 45 lb N/acre was applied at panicle initiation and the remainder of the N recommendation was applied preflood at <5 days before permanent flood. The N-STaR SPF N recommendations were all applied preflood at <5 days before permanent flood. The N-STaR SPF N recommendations were 20 lb N/acre less than the N-STaR 2-WS N recommendation calculated by the 95% and 100% RGY calibration curves. The N fertilizer applied was urea treated with the urease inhibitor N-(n-butyl) thiophosphoric triamide (NBPT); trade name Agrotain Ultra®, (Koch Fertilizer LLC., Wichita, Kan.). Grain was harvested from the middle four rows of each plot and weights were adjusted to 12% grain moisture and expressed in bushels (bu)/acre. Rough rice grain yield was compared across treatments within a location using JMP Pro 11.0 (SAS Institute, Inc., Cary, N.C.) using Fishers protected least significant difference test at the $P = 0.05$ level.

RESULTS AND DISCUSSION

The standard N recommendation currently used by Arkansas rice producers is altered according to cultivar, soil texture, and previous crop. The introduction of N-STaR allowed producers to test for an index of potentially mineralizable N that was calibrated to a site-specific N recommendation. Two N-STaR calibration curves, the 95% RGY and the 100% RGY, were developed for use in clay soil that would provide site-specific N-rate recommendations needed to obtain the respective percentage (95% or 100%) of yield on a field by field basis. Historically, the 95% and 100% RGY N fertilizer recommendations have not been significantly different with regard to yield, although, the 100% RGY is often numerically higher (Roberts et al., 2013; Davidson et al., 2014). The substantially larger N-rate recommendation predicted by the 100% RGY reflects the high cost to the producer in achieving the last 5% of rice yield.

In order to reduce variability across locations, the RGY of the five N fertilizer recommendations was compared at each of the seven sites as shown in Table 1. The 2-WS N-STaR 100% RGY was statistically similar to the standard N recommendation for five of the seven sites. At Site ES-3, the 2-WS N-STaR 100% RGY was significantly lower than the standard N recommendation, however, the yield decrease was relatively small at 15 bu/acre. At this location, the SPF N rate resulted in a greater yield compared to the 2-WS N rate within the 95% and 100% RGY N-rate recommendations. This likely resulted from adverse environmental conditions causing preflood N losses since previous studies conducted at this location by Davidson et al. (2014) showed the 2-WS to perform as well or better than the SPF. The 2-WS N-STaR 100% RGY treatment yielded significantly higher than the standard N recommendation at Site P-7. Site P-7 was unique in that it had a N-STaR recommendation of 0 lb N/acre for both the 95% and 100% RGY calibration curves and, therefore, will be discussed separately in detail.

With the 2-WS N-STaR 95% RGY, N rates ranged from 0 to 150 lb N/acre. Site P-5 did not receive a 2-WS N-STaR 95% RGY treatment since the total fertilizer-N

rate was small and not economical to split apply in a production setting. Five of the six sites receiving a 2-WS N-STaR 95% RGY yielded equal to (P-6, P-8, ES-4, and ES-5) or significantly greater than (P-7) the standard N recommendation. The 2-WS N-STaR 95% RGY at Site ES-3 yielded significantly lower than the standard N recommendation at a magnitude of 38 bu/acre.

When the 2-WS N-STaR 95% and 100% RGY treatments were compared, only ES-3 showed a statistical difference with the 100% RGY yielding higher than the 95% RGY. Overall, the 2-WS N-STaR 95% RGY is able to achieve similar yields compared to the 100% RGY while applying less total fertilizer N and reflects results reported by Roberts et al. (2013) and Davidson et al. (2014). The 95% and 100% RGY option allows producers to select the N fertilizer strategy that best fits their nutrient management philosophy and capabilities.

Research conducted by Wilson et al. (1989) has shown that N applied as a preflood application can have a very high fertilizer N use efficiency. Under optimum conditions, the SPF application translates into less N applied by the grower and potentially lower application costs. The SPF N-STaR application rates for clay soil were calculated using the 2-WS N-STaR 95% or 100% RGY N-rate calibration curves and then subtracting a constant of 20 lb N/acre from the total N rate. For six of the seven sites, the SPF N-STaR 100% RGY was statistically similar or greater than the standard N recommendation while the N rate difference ranged from 40 to 200 lb N/acre less than the standard N recommendation. The SPF N-STaR 100% RGY at Site P-5 numerically yielded the lowest out of all N treatments and was statistically lower than the standard N recommendation as well as the 2-WS 100% RGY at a magnitude of 21 and 22 bu/acre, respectively. The remaining six sites had no statistical differences between the SPF N-STaR 100% RGY and the 2-WS N-STaR 100% RGY, although the SPF numerically averaged 4 bu/acre less in yield than the 2-WS.

The SPF N-STaR 95% RGY recommended a N rate that ranged from 0 to 130 lb N/acre. For the SPF N-STaR 95% RGY, six of the seven sites were statistically similar (Sites P-5, P-6, P-8, ES-4, and ES-5) or greater than (Site P-7) the standard N recommendation. At Site ES-3, the SPF N-STaR 95% RGY yielded 23 bu/acre less than the standard N recommendation, although it did yield statistically greater than the 2-WS N-STaR 95% RGY at a magnitude of 15 bu/acre. The SPF and 2-WS N-STaR 95% RGY treatments were statistically similar at all other locations. When the 95% RGY SPF and 2-WS are examined at sites that were statistically similar, the SPF application tended to have a larger yield decrease than the 2-WS application when compared to the standard N recommendation. The yield for the SPF 95% RGY was numerically lower than the standard N recommendation at four of the five sites and yields ranged from -17 to 16 bu/acre. Alternatively, the 2-WS 95% RGY yielded numerically lower than the standard N recommendation at two of four sites with yields ranging from -6 to 14 bu/acre. In general, the SPF tended to produce comparable yields to the 2-WS for the N-STaR 95% RGY.

Site P-7 was unique in that the N-STaR value was very high which resulted in 2-WS and SPF N-STaR 95% and 100% RGY N recommendations that were 0 lb N/acre. In order to verify the N-STaR recommendation, alternate N rates of 25, 45, 75, and 90 lb N/acre were included in the trial along with the check plot and the standard N recommendation. For Site P-7, the check plot received 0 lb N/acre while the standard N recommendation received 200 lb N/acre, yet the check plot yielded statistically higher than the standard N recommendation at a magnitude of 72 bu/acre. Excess N has been known to decrease yields through lodging or by increased disease or pest pressure. In this case, yield differences between the check and the standard N recommendation were caused by heavy lodging. When compared to the alternate N treatments, the check plot yielded statistically higher than the 90 lb N/acre alternate rate and statistically similar to the remaining alternate rates. Overall, the N-STaR recommendation of 0 lb N/acre (check plots) yielded the highest with yields tending to decrease with increasing N fertilizer rates.

Site P-7 was in a field adjacent to Site P-8 and a comparison of the N recommendation predictions show the importance of sampling each field separately when using N-STaR. The N-STaR N recommendations at Site P-8 ranged from 95 to 145 lb N/acre, while the N-STaR N recommendations at Site P-7 were 0 lb N/acre. In both cases, the N-STaR N recommendation maximized yield and profitability. Following specified sampling protocols is vital in maintaining the effectiveness of the N-STaR N recommendations, and therefore teaching correct procedures is of utmost importance.

SIGNIFICANCE OF FINDINGS

The N-STaR is the first soil-based N test for rice in Arkansas and accurately indexes the mineralization potential of clay soil during rice production. In this study, the 2-WS and SPF N-STaR 95% and 100% RGY calibration curves all produced statistically similar results with six of seven sites yielding equal to or greater than the standard N recommendation. This is different from the previous study conducted by Davidson et al. (2014) where the SPF N-STaR 95% RGY yielded statistically lower than the standard N recommendation at half of the locations and where there were no statistical differences between the 2-WS or SPF N-STaR 100% RGY treatments and the standard N recommendation. Overall, N-STaR has the ability to optimize productivity through maximum yields and typically lower N input costs as seen in this study. The agronomic value of the N-STaR N recommendations will continue to grow as N fertilizer prices and concerns of agricultural pollution continue to increase.

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Table 1. Comparison of the 2-way split (2-WS) N-STaR 95% and 100% relative grain yield (RGY), single preflood (SPF) N-STaR 95% and 100% RGY and standard (Std. Rec.) fertilizer N rate recommendations and the resulting rice grain yields for the four producer (P) and three experiment station (ES) sites utilized in 2015.

Fertilizer N-rate recommendation	P-5		P-6		P-7		P-8	
	N Rate	Yield	N Rate	Yield	N Rate	Yield	N Rate	Yield
	(lb N/acre)	(bu/acre)	(lb N/acre)	(bu/acre)	(lb N/acre)	(bu/acre)	(lb N/acre)	(bu/acre)
Check	0	129 c[‡]	0	149 b	0	221 a	0	172 b
SPF 95% RGY[†]	65	157 ab	80	179 a	25[§]	212 ab	95	217 a
2-WS 95% RGY	-	-	100	186 a	45[§]	205 ab	115	215 a
SPF 100% RGY	75	153 b	110	183 a	75[§]	214 ab	125	214 a
2-WS 100% RGY	95	175 a	130	195 a	90[§]	200 b	145	216 a
Std. Rec.	170	174 a	170	190 a	200	149 c	200	201 a

Fertilizer N-rate recommendation	ES-3		ES-4		ES-5	
	N Rate	Yield	N Rate	Yield	N Rate	Yield
	(lb N/acre)	(bu/acre)	(lb N/acre)	(bu/acre)	(lb N/acre)	(bu/acre)
Check	0	78 e	0	89 b	0	109 c
SPF 95% RGY	95	169 c	130	162 a	130	226 b
2-WS 95% RGY	115	154 d	150	169 a	150	238 ab
SPF 100% RGY	125	186 ab	160	166 a	160	244 ab
2-WS 100% RGY	145	177 bc	180	171 a	180	256 a
Std. Rec.	180	192 a	200	175 a	200	236 ab

[†] RGY = Relative Grain Yield.

[‡] Means within a column followed by a different superscript letter are significantly different at the $P = 0.05$ level.

[§] N-STaR recommendation was for no N fertilizer to be applied at this site. However, alternate SPF N rates of 25, 45, 75, and 90 lb N/acre were applied to ensure that there would be no response to N fertilizer addition.

Evaluation of Alternative Nitrogen Fertilizer Application Timings in Four Water Management Regimes

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ABSTRACT

Approximately 96% of Arkansas rice is grown using the dry-seeded, delayed-flood system. In this system, nitrogen (N) fertilizer is applied to the crop as a single preflood (SPF) or two-way split (2WS) application. The large preflood N application is made around the 4- to 6-lf growth stage and the second application, if needed, is applied during early reproductive growth. Regardless of N fertilization strategy, the preflood N application should be made onto dry soil and incorporated with the floodwater to obtain maximum uptake of the preflood N fertilizer. In recent years, there has been increased interest in using alternative water management practices as a possible means to save water resources and lower input costs. The question has arisen of how water practices might affect N management and whether currently recommended N application methods are the best for water regimes other than the continuous flood system. Therefore, a study was initiated in 2014 to determine the effect of alternative N fertilization practices and the recommended optimum (single preflood) N application timing on rice grain yield within each of four water management regimes using cultivars commonly grown in Arkansas. Studies were conducted on a DeWitt silt loam soil using N-(n-butyl) thiophosphoric triamide (NBPT)-coated urea as the N source. Rice cultivars evaluated included Roy J and CLXL745 in 2014 and LaKast and XL753 in 2015. When the rice reached the 4- to 5-lf growth stage, four water management regimes were implemented: continuous flood (CF), straighthead drain (SD), intermittent flood (IF), and flush (FL) irrigation. Plots received either a SPF N application to dry soil prior to permanent flood establishment or a split N application based on water regime. During 2014 and 2015, there was no cultivar × N timing interaction. Grain yield was optimized in both study years using a SPF N application applied to dry soil and water-incorporated in the continuous flood regime. Grain yield was comparable between N application timings in the straighthead

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drain and flush irrigated water regimes. Grain yield was optimized in the intermittent flood regime using a split fertilizer application consisting of 120 lb N/acre applied prior to flooding followed by 30 lb N/acre applied early in reproductive growth.

INTRODUCTION

Approximately 96% of Arkansas rice is grown using the dry-seeded, delayed-flood system (Hardke, 2015). In this system, nitrogen (N) is applied at the 4- to 6-lf growth stage using urea or ammonium sulfate onto a dry soil surface prior to permanent flood establishment (Norman et al., 2013). The preflood N can be applied as a single application, termed "single preflood" (SPF) or may be split into two timings commonly referred to as a "2-way split" (2WS) with approximately 75% of the total N rate being applied preflood and the remaining 45 lb N/acre applied after the rice has begun reproductive growth. These two options are based on field conditions such as the timeliness of flood establishment and the ability to maintain an adequate flood for a minimum of 3 weeks. Also, establishing a permanent flood serves two purposes: (1) the ammonium fertilizer is pushed into the soil profile where it can be taken up by the rice roots, and (2) the flood maintains an anaerobic environment where the fertilizer is not lost due to ammonia volatilization or nitrification/denitrification processes.

In recent years, there has been increased interest in using alternative water management practices as a possible means to save water resources and lower input costs. The question has arisen of how water practices might affect N management and whether our currently recommended N application methods are the best for water regimes other than the continuous flood system. Therefore, a study was initiated in 2014 to determine the effect of alternative N fertilization practices and the recommended optimum (single preflood) N application timing on rice grain yield within each of four water management regimes using cultivars commonly grown in Arkansas.

PROCEDURES

Studies were conducted during 2014 and 2015 at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center near Stuttgart, Ark., on a DeWitt silt loam soil using N-(n-butyl) thiophosphoric triamide (NBPT)-coated urea as the N source. The rice was grown using the dry-seeded, delayed-flood system using cultural management practices common to this system. During 2014, the rice cultivars Roy J and RiceTec CLXL745 were seeded on 24 April, emerged 10 May, and the permanent flood established on 6 June. During 2015, the cultivars LaKast and RiceTec XL753 were seeded 6 May, emerged 15 May and the permanent flood established 10 June. The pure-line varieties, Roy J and LaKast, were drill-seeded at a rate of 75 lb seed/acre in plots 9 rows (7-inch spacing) wide and 15 ft in length. The hybrid entries, CLXL745 and XL753 were sown into the same plot configuration using a seeding rate of 30 lb seed/acre.

At the time of flood establishment when the rice reached the 4- to 5-lf growth stage, four water management regimes were implemented: continuous flood (CF), straighthead

drain (SD), intermittent flood (IF), and flush (FL) irrigation. The CF bay flood depth was maintained at approximately 4 inches until just prior to harvest. The SD bay was flooded to the same depth for approximately 10 days then drained and allowed to dry until the soil was cracked in keeping with recommended practices for management of straighthead disorder. The bay was then re-flooded based on suggested dates from the DD50 program and maintained at 4 inches until just prior to harvest. These dates in the DD50 program for a drain/dry period are based on heat unit accumulation during the growing season and are timed to reduce the potential for straighthead in susceptible cultivars. The IF bay was also flooded to a depth of 4 inches but additional water was added to this bay only when the soil moisture level dropped to a predetermined level of approximately 20 centibars using soil moisture sensors. These sensors were also used in the FL bay to determine water needs. A flood was applied and held on this bay for 12 to 24 hours each time the water moisture sensor reached 20 centibars. This period was determined to be the time required for the sensor reading to drop back to 0 centibars.

Plots were arranged as a 2 (cultivar) × 2 (N timing) factorial within each water management regime. Plots received either a recommended SPF N application to dry soil prior to permanent flood establishment or a split N application based on water regime. The split N application timing made to the CF bay consisted of a series of five applications of 45 lb N/acre into the floodwater beginning 1 day postflood at 7 day intervals. During 2015, an additional application of 30 lb N/acre was applied at late boot to the hybrid XL753. The SD bay split N timing plots received one application of 60 lb N/acre preflood followed by 60 lb N/acre applied just prior to re-flooding. Each plot in the IF bay received the same preflood N application but the split N timing plots received an additional 30 lb N/acre applied to damp soil just prior to re-flooding after reaching the low soil moisture level to reflood. The split N timing plots in the FL water regime received 60 lb N/acre at the same preflood application time as the other three water regimes but the flood was only held 12 to 24 hours during each irrigation event, then released. A second N application was made 10 days after the preflood N was applied, when the soil moisture was at 20 centibars, and an irrigation event was used to incorporate the urea into the soil. Statistical analysis were conducted with SAS 9.4 (SAS Institute Inc., Cary, N.C.) and means were separated using Fisher's protected least significant difference test with $P = 0.05$.

RESULTS AND DISCUSSION

During 2014 and 2015, there was no cultivar × N timing interaction in any of the four water management regimes. Only the main effect of N application timing was significant. It should be noted that grain yield data was not combined across years to be able to look at individual data sets from two dissimilar growing seasons.

In the CF water management regime, grain yield was optimized in both 2014 and 2015 using a SPF N application applied to dry soil and flood-incorporated (Tables 1 and 2). Average grain yield was similar regardless of N application timing in the SD regime. These results suggest that a properly timed drain for management of straighthead disorder can be achieved without yield loss and that N fertility may be more flexible in

this situation. However, it should be noted that this trial was not conducted in an area prone to straighthead disorder; the results simply indicate that the prescribed drain can be completed without sacrificing yield regardless of whether straighthead conditions are present.

Interestingly, grain yield was greater during 2014 and 2015 using the split N application timing in the IF water management regime. As noted above, all plots received the same preflood N rate prior to flooding. In 2014 a standing flood was lost early but regular rainfall prevented the soil from reaching the low soil moisture level needed to re-flood, and the second portion of the split N application was not made until 3 July, 27 days after initial flood establishment. In 2015 the trial quickly reached the low soil moisture level of 20 centibars and was re-flooded just 12 days after the initial flood, and the second portion of the split N application wasn't made until 1 July, 21 days after initial flood establishment. The timing of the second N application corresponds to studies by Wilson et al. (1989) showing peak fertilizer N uptake occurred within 21 days of permanent flood and remained steady through the 28 day sampling period. However, when the permanent flood is lost and re-established prior to peak fertilizer N uptake at ~21 days, N loss can occur and the (split) N application used in this trial may have acted as a supplement for N lost prior to the time of peak uptake. The results of the IF water regime in this study helped to emphasize current recommendations to maintain the initial permanent flood for at least 3 weeks before beginning the alternate wet and dry periods used in the intermittent flood system (Wilson et al., 1989).

Grain yield was similar between the two N timings in the FL water regime during both study years. Although comparisons between water management regimes were not made for the scope of this report, numerical grain yields obtained in the FL water regime were notably lower than those of the other three. In many "row rice" or furrow-irrigated fields in Arkansas, producers have been able to obtain yields similar to those seen in fields where a continuous flood is maintained throughout the growing season. The low yields reflected in the FL bay are representative of only a small portion of fields irrigated with a flush/furrow system as the middle and bottom of the fields typically remain saturated or flooded while the upper portion alone is "flushed". Adjustments in experimental design are needed before pursuing further research in best management practices for furrow-irrigated rice to better represent in-field soil moisture variation.

It should be noted there were no blast disease symptoms in the study during either 2014 or 2015 that would have had a negative impact on grain yield. Blast disease pressure is greater in fields where a deep flood cannot be maintained and has the potential to negatively impact grain yield in fields using water management practices of alternate wetting and drying such as the IF and FL water regimes.

SIGNIFICANCE OF FINDINGS

Results from the water management study will aid University of Arkansas System Division of Agriculture personnel in answering grower questions concerning the best way to fertilize rice grown using alternate water management regimes.

ACKNOWLEDGMENTS

This and other studies are supported by the University of Arkansas System Division of Agriculture and through grower check-off funds administered by the Arkansas Rice Research and Promotion Board. We wish to thank the following people for their dedication to making these studies possible each year: Chuck Pipkins, Taylor Roush, Logan Stokes, and Greg Wilson.

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Table 1. Influence of nitrogen (N) fertilizer application timing on rice grain yield among four water management regimes at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center near Stuttgart, Ark., during 2014.

	Water management regime			
N timing	**Continuous flood**	**Straighthead drain**	**Intermittent flood**	**Flush**
	----------(bu/acre)----------			
SPF N[a]	191	193	184	143
Split N[b]	153	193	198	145
$LSD_{0.05}$[c]	19.6	NS[d]	12.3	NS

[a] Single preflood nitrogen application, 120 lb N/acre applied to dry soil prior to flooding.
[b] Continuous flood: 5 applications of 46 lb N/acre applied once every 7 days for 5 weeks beginning at flood; Straighthead drain: 60 lb N/acre preflood and 60 lb N/acre before reflood following drain; Intermittent flood: 120 lb N/acre preflood plus 30 lb N/acre approximately 3 weeks later before reflood; and Flush: 60 lb N/acre preflood and 60 lb N/acre 10 days later.
[c] LSD = least significant difference.
[d] NS = not significant.

Table 2. Influence of nitrogen (N) fertilizer application timing on rice grain yield among four water management regimes at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center near Stuttgart, Ark., during 2015.

	Water management regime			
N timing	**Continuous flood**	**Straighthead drain**	**Intermittent flood**	**Flush**
	----------(bu/acre)----------			
SPF N[a]	239	235	219	168
Split N[b]	210	236	235	162
$LSD_{0.05}$[c]	14.5	NS[d]	12.3	NS

[a] Single preflood N application of 120 lb N/acre applied to dry soil prior to flooding.
[b] Continuous flood: 5 applications of 46 lb N/acre applied once every 7 days for 5 weeks beginning at flood; Straighthead drain: 60 lb N/acre preflood and 60 lb N/acre before reflood following drain; Intermittent flood: 120 lb N/acre preflood plus 30 lb N/acre approximately 3 weeks later before reflood; and Flush: 60 lb N/acre preflood and 60 lb N/acre 10 days later.
[c] LSD = least significant difference.
[d] NS = not significant.

Effect of Delayed Nitrogen Fertilization into the Floodwater

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ABSTRACT

Nitrogen (N) fertilizer (typically urea or ammonium sulfate) is applied in the dry-seeded, delayed-flood system common to Arkansas rice production as a single preflood (SPF) or two-way split (2WS) application. The large preflood N application is made around the 4- to 6-lf growth stage onto dry soil and the second application, if needed, is applied during early reproductive growth. Rainy weather in recent years during the recommended window of application have made the likelihood of dry soil conditions unlikely and questions have arisen concerning the best management strategy to preserve rice grain yield and optimize N efficiency in those fields. Therefore, a study was initiated in 2015 to address these concerns. Treatments to LaKast rice consisted of the recommended SPF with all N applied preflood onto dry soil, a suboptimum 2WS option with a reduced preflood N rate (to mimic wet soil conditions) applied to dry soil followed by midseason N, variations of sequential fertilizer applications into the floodwater, and a no-N fertilizer check. Treatments were initiated based on dates noted from a DD50 report generated for this study. The SPF N fertilizer application resulted in significantly higher grain yield than the 2WS treatment. Both of these options produced grain yields significantly higher than any of the treatments made only into the floodwater.

INTRODUCTION

Approximately 96% of Arkansas rice is grown using the dry-seeded, delayed-flood system (Hardke, 2015). In this system, nitrogen (N) is applied at the 4- to 6-lf growth stage using urea or ammonium sulfate onto a dry soil surface prior to permanent flood establishment (Norman et al., 2013). The preflood N can be applied as a single application, termed "single preflood" (SPF) or may be split into two timings

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commonly referred to as a "2-way split" (2WS) with approximately 75% of the total N rate being applied preflood and the remaining 45 lb N/acre applied after the rice has begun reproductive growth. These two options are based on field conditions such as the timeliness of flood establishment and the ability to maintain an adequate flood for a minimum of 3 weeks. Also, establishing a permanent flood serves two purposes: (1) the ammonium or ammonium forming N fertilizer is moved into the soil profile with the wetting front where it can be taken up by the rice roots, and (2) the flood maintains an anaerobic environment where the N fertilizer is not lost due to ammonia volatilization or nitrification/denitrification processes.

Occasionally, questions arise concerning the presence of muddy or flooded field conditions in the recommended window for preflood N fertilizer application. Therefore, a study was initiated in 2015 to determine the best management strategy for applying N fertilizer in fields where weather conditions prevent dry soil conditions.

PROCEDURES

A study was initiated during 2015 utilizing N-(n-butyl) thiophosphoric triamide (NBPT)-coated urea applied to LaKast rice at various application timings. The study was conducted at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center near Stuttgart, Ark., on a DeWitt silt loam soil. The rice was drill-seeded at a rate of 75 lb seed/acre in plots 9 rows (7-inch spacing) wide × 15 ft in length on 15 May, emerged 22 May, and the permanent flood established 11 June. Cultural management practices used were standard to the dry-seeded, delayed-flood production system. Nitrogen fertilizer treatments evaluated are listed in Table 1 and consisted of the recommended SPF and 2WS options with the preflood N applied to dry soil, variations of sequential fertilizer applications into the floodwater, and a no-N fertilizer check. The 2WS treatment was modified so that a reduced preflood N rate was used to mimic N loss due to application onto wet soil. Treatments were initiated based on dates noted from a DD50 report generated for this study. One treatment made solely into the floodwater was initiated 1 day following permanent flood establishment. The remaining treatments made into the floodwater were initiated at the final recommended date to apply preflood N as determined by heat unit accumulation in the DD50 program which occurred approximately 10 days after flooding. The study was arranged as a randomized complete block and means were separated using Fisher's protected least significant difference test with $P = 0.05$.

RESULTS AND DISCUSSION

During this initial study year, the SPF N fertilizer treatment resulted in significantly higher grain yield than the 2WS treatment (Table 1). The recommended 2WS treatment would normally receive 25 lb N/acre more than the SPF treatment; however, in this study the rate was reduced to simulate an ineffective preflood N application to muddy soil. As a result, the 2WS treatment for this study was determined by subtracting

the standard midseason N rate of 45 lb N/acre from the SPF rate of 120 lb N/acre. The remaining 75 lb N/acre was applied at preflood onto dry soil followed by the standard midseason N rate of 45 lb N/acre into the floodwater at beginning reproductive growth. Both the SPF and 2WS treatments produced grain yields higher than any of the treatments made only into the floodwater. Of N applications made into the floodwater, all of those treatments that were delayed and initiated at the final preflood application time according to the DD50 report produced greater yields than the treatment initiated at 1 day after flood establishment. For the delayed in-flood treatments, application of 45 lb N/acre every 7 d (total of 5 applications) resulted in the greatest grain yield compared to all treatments except the SPF and 2WS treatments. These results suggest that the SPF treatment applied to dry soil continues to be the best option for N fertilizer management; and the 2WS treatment in this study (designed to mimic preflood N application to muddy soil) is still a better option than the "spoonfeed" approach of N applications into the standing flood.

SIGNIFICANCE OF FINDINGS

Results from this study will aid University of Arkansas System Division of Agriculture personnel in answering grower, agent and consultant questions concerning N management decisions on rice fields where the preflood N fertilizer cannot be applied according to University of Arkansas System Cooperative Extension Service recommendations onto a dry soil surface.

ACKNOWLEDGMENTS

This and other studies are supported through grower check-off funds administered by the Arkansas Rice Research and Promotion Board and are much appreciated. Also, we appreciate the funding and support from the University of Arkansas System Division of Agriculture. We wish to thank the following people for their dedication to making these studies possible each year: Chuck Pipkins, Taylor Roush, Logan Stokes, and Greg Wilson.

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Table 1. Influence of nitrogen (N) fertilizer application timing on the grain yield of LaKast rice at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center near Stuttgart, Ark. during 2015.

Treatment no.	N timing	N application Frequency[†]	N application Rate	Total N fertilizer applied	Grain yield
			---------- (lb N/acre) --------		(bu/acre)
1	Control	none	0	0	71 g[‡]
2	SPF	PF	120	120	186 a
3	2WS	PF fb MS	75+45	120	165 b
4	Flood initiation[§]	7-8d intervals	5 @ 45[¶]	225	117 f
5	Final DD50[#]	4-5d intervals	5 @ 45	225	141 d
6	Final DD50	7-8d intervals	5 @ 45	225	155 c
7	Final DD50	4-5d intervals	4 @ 60	240	138 d
8	Final DD50	7-8d intervals	4 @ 60	240	140 d
9	Final DD50	4-5d intervals	45+60+60+45	210	127 e
$LSD_{0.05}$[††]					7.6

[†] PF = preflood, fb = followed by, and MS = midseason.
[‡] Means followed by the same letter are not significantly different (*P* = 0.05).
[§] One day postflood (12 June -- two days after initial recommended date to apply preflood N fertilizer when rice has reached 4- to 5-lf growth stage based on DD50 Rice Management Program).
[¶] 5 @ 45 represents 5 applications of 45 lb N/acre at each application.
[#] Final DD50 = final recommended date (i.e., 10 days postflood) to apply preflood N fertilizer (22 June for this trial) based on DD50 Rice Management Program.
[††] LSD = least significant difference.

Validation of Soil-Test Based Fertilizer Recommendations for Rice

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ABSTRACT

Fertilizer recommendations for phosphorus (P) and potassium (K) are often based on soil-test results, but recommended fertilizer nutrient rates may differ among labs or consultants providing the recommendations. The research objective was to validate the accuracy of the existing University of Arkansas System Division of Agriculture (UASDA) soil-test based fertilizer-P and -K recommendations for predicting rice (*Oryza sativa* L.) yield response to fertilization. Eight trials were established at four UASDA research centers/stations in 2015. Statistical comparisons were evaluated at three significance levels ($P \leq 0.05$, 0.10, and 0.25) to validate the existing recommendations. The treatments evaluated rice yield response to: i) with vs without fertilizer-P, ii) with vs without fertilizer-K, and 3) the recommended fertilizer-P and -K rates compared to no fertilizer-P and -K. The overall soil-test interpretation accuracy ($P \leq 0.25$) of predicting the correct rice yield response was 40% to fertilizer-P and 75% for -K. The level of significance at which results were interpreted affected the accuracy only for K (decreased to 50% at $P \leq 0.10$). The most common error in recommendations was a 'false positive' meaning the soil-test interpretation indicated the need for fertilizer but crop yield was not increased.

INTRODUCTION

Fertilizer recommendations for P and K are usually based on soil-test results, but recommended fertilizer nutrient rates from the same soil analysis may differ among the laboratories or consultants providing the recommendation (Kleinman et al., 2001). Differences in nutrient management philosophy, poor understanding of the dynamics of

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soil nutrient availability and how fertilizer recommendations are developed, misconceptions of the accuracy of the soil-test-based recommendation, or combinations of these and other factors contribute to confusion among the end-users of soil-test information.

An ongoing project has been evaluating the accuracy of existing fertilizer-P and -K recommendations of the University of Arkansas System Division of Agriculture (UASDA) to identify where adjustments might be needed to make predictions regarding what nutrients are needed and how much to apply more accurately (Fryer, 2015). Information included in this report summarizes the third and final year of the research. The overall goal of the research was to improve the accuracy of soil-test based P and K fertilizer recommendations for flood-irrigated rice. The objective of research presented in this report was to evaluate whether rice responded to the: i) currently recommended fertilizer-P and -K rates, ii) recommended fertilizer-P rate alone, and iii) recommended fertilizer-K rate alone, all compared to rice that received no fertilizer-P or -K. The yield of rice was expected to benefit from fertilization when soil-test P and K levels were Very Low, Low, or Medium and no yield increase was predicted when soil-test levels were Optimum or Above optimum.

PROCEDURES

Eight fertilization trials were established at four UASDA research center/stations during 2015 including the Northeast Research and Extension Center (NEREC), Pine Tree Research Station (PTRS), Rice Research and Extension Center (RREC), and Rohwer Research Station (RRS). Soil and agronomic information as well as the field name used for each site in this report are listed in Table 1. Initial soil samples were collected in the spring to define the UASDA fertilizer treatments at each site. Individual plots of rice were 9 rows wide (~5.6-ft wide) × 18- to 20-ft long. Plot borders were marked and 0- to 4-in. deep samples were taken from each replicate (n = 6). Plant-available, soil nutrients were extracted using the Mehlich-3 solution and determined analytically by inductively coupled plasma spectroscopy. Selected soil chemical property means are listed in Table 2.

Each trial contained a total of six treatments with four K_2O rates (0, 60, 90 and 120 lb K_2O/ace) and two P_2O_5 (0 and 60 lb P_2O_5/acre) rates including: 1) the recommended P_2O_5 rate plus 0 lb K_2O/acre, 2) the recommended P_2O_5 rate plus 60 lb K_2O/acre, 3) the recommended P_2O_5 rate plus 90 lb K_2O/acre, 4) the recommended P_2O_5 rate plus 120 lb K_2O/acre, 5) the recommended K rate plus the second P_2O_5 rate, and 6) no P_2O_5 or K_2O fertilizer (control). The six treatments in each trial were organized as a randomized complete block design with six blocks. Crop management practices closely followed recommendations from the UASDA Cooperative Extension Service. Urea-nitrogen (N) fertilizer treated with a urease inhibitor was applied using the N-STaR recommended rate near the 5-lf stage and the rice was flooded. Additional N was applied to some sites at midseason based on a visual assessment of growth and knowledge of the soil conditions when preflood-N was applied.

Whole aboveground plant samples were collected from selected plots at the midtillering and early heading stages to assess plant P and K concentrations. A harvested seed

sample was collected from each plot at maturity. Plant and seed samples were weighed, digested, and analyzed for nutrient concentrations, but the results will not be reported here. A small plot combine harvested 5 to 8 of the 9 rows in each plot. Weights and moistures were recorded, and rice grain moisture was adjusted to 12% in the final yield calculations which are expressed in bushels (bu)/acre.

Three single-degree-of-freedom contrasts were performed using the MIXED procedure in SAS v. 9.2 (SAS Institute Inc., Cary, N.C.) to evaluate grain yield differences. Specific comparisons were made by comparing rice plots receiving: 1) fertilizer-P (no K), 2) fertilizer-K (no P), and 3) the recommended fertilizer-P and -K rates all compared to the rice that received no fertilizer-P or -K. Three levels of significance ($P \leq 0.05$, 0.10, and 0.25) were used to define yield differences. Fertilization effects on rice yield were categorized as a yield increase, no yield change, or yield decrease. The hypothesis was that soils with Very Low, Low, and Medium P and K levels would show a yield increase to fertilizer, and soils with Optimum and Above Optimum P and K levels would show no change in yield. For sites with Medium soil-test P and K levels, smaller and less frequent yield increases were expected. A yield decrease was not expected from P and K fertilization in any soil-test level, but it was included as a possible outcome.

RESULTS AND DISCUSSION

Fertilization studies were conducted at six loamy soil sites and two clayey soil sites in 2015 (Table 1). The two clayey soils (NEREC and RRS-CL) were the only two sites where no yield increase was expected from fertilizer-P, fertilizer-K, or their combination (Table 2). At the six loamy sites (PTRS-I10, PTRS-L2, PTRS-MJC, PTRS-F18, RRS-SL, and RREC), the soil-test level interpretations suggested that rice grain yield would increase from the application of both P and K. Rice yield was not affected by P and K fertilization at the two clayey sites which had Optimum (NEREC) or Above Optimum (RRS-CL) soil-test P and Above Optimum soil-test K (NEREC and RRS-CL; Table 3). Rice grain yield was not changed by fertilizer-P application at the six loamy soil sites, which contained suboptimal soil-test P levels, when evaluated at $P \leq 0.05$ and 0.10, but when evaluated at $P \leq 0.25$, rice yield at PTRS-I10 was reduced by 4.6% (9 bu/acre) compared to rice that received no fertilizer-P or -K.

Soil-test K levels were Very Low (PTRS-L2), Low (PTRS-I10), or Medium (PTRS-MJC, PTRS-F18, RRS-SL, and RREC) for the six loamy soil sites (Table 2). Grain yield responses to fertilizer-K occurred at one (PTRS-I10; $P \leq 0.05$) or two (PTRS-I10 and PTRS-L2; $P \leq 0.25$) of the six loamy sites (Table 3). The average yield increase to K fertilization at the two responsive sites was 11 bu/acre or 6.1%. The four remaining sites with suboptimal soil-test K levels did not have significant yield changes from K fertilization. Rice yield response to the recommended combination of fertilizer-P and -K on the six loamy soils depended on significance level and showed that one (PTRS-L2; $P \leq 0.05$) or four (PTRS-L2, PTRS-I10, PTRS-MJC, and PTRS-F18; $P \leq 0.25$) of the sites responded positively to fertilization, with an average increase of 8 bu/acre or 4.6%.

SIGNIFICANCE OF FINDINGS

Table 4 shows the overall accuracy of the soil-test interpretations. The accuracy of soil-test P interpretation (40%) was not affected by the level of significance used in the evaluation, with all of the error occurring in the suboptimal soil-test P levels where a yield increase was expected (false positive error). Like soil-test P, all of the error in the soil-test K interpretation occurred within the suboptimal level, but the amount of error decreased when results were evaluated at the 0.25 significance level. Soil-test K was 50% ($P \leq 0.05$ and 0.10) to 75% ($P \leq 0.25$) accurate. The existing soil-test K recommendations appear to work reasonably well on soils with Low and Very Low K levels and serve to maintain K fertility on the soils that test Medium. Although the tissue K results were not included in this report, the results showed that rice-K concentrations have a strong correlation with soil-test K, which agrees with prior research (Slaton et al., 2009; Fryer, 2015). When the overall (P and K) soil-test recommendation was compared to the no-fertilizer control, accuracy was numerically greater (58% to 83% at $P \leq 0.05$ and ≤ 0.25, respectively) than the evaluations made to P or K only, but the results tended to mimic the fertilizer-K response tendencies. Overall, when soil-test P or K was Optimum or Above Optimum, soil-test interpretations were 100% accurate, indicating false negative errors seldom occur for properly collected soil samples. Soil-test P levels should be lowered to encompass the error that occurs in the suboptimal levels.

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Table 1. Selected soil and agronomic information for eight rice fertilization trials conducted at multiple sites during 2015.

Site[a]	Soil series	Cultivar	Row width	Planting date	Previous crop and fertilizer[b]		
					Crop	P_2O_5	K_2O
			(in.)			-------- (lb/acre) ------	
PTRS-I10	Calloway	Roy J	7.5	30 April	Soybean	0	0
PTRS-L2	Calloway	CL111	7.5	1 May	Soybean	0	0
PTRS-MJC	Calhoun	CL172	7.5	8 April	Fallow	0	0
PTRS-F18	Calhoun	Roy J	7.5	30 April	Soybean	0	0
RRS-SL	Desha	CL172	7.0	5 May	Soybean	0	0
RREC	Dewitt	LaKast	7.0	1 May	Soybean	40	60
NEREC	Sharkey	CL172	7.0	6 May	Soybean	0	0
RRS-CL	Sharkey/Desha	CL172	7.0	5 May	Rice	0	0

[a] Abbreviations include: NEREC, Northeast Research and Extension Center; PTRS, Pine Tree Research Station; RREC, Rice Research and Extension Center; and RRS, Rohwer Research Station. The letter or letters after the site abbreviation represent the field name.

[b] Crop grown and fertilizer applied during the 2014 growing season.

Table 2. Selected soil (0- to 4-in. depth) chemical property means (n = 6) from the unfertilized control in eight phosphorus (P) and potassium (K) fertilization trials during 2015.

		Soil test level[b]		4-in. depth sample[c]						
Site[a]	pH	P	K	P	K	Ca	Mg	S	Zn	SOM
				----------(ppm)----------						(%)
PTRS-I10	7.2	Low	Low	25 (3)	66 (3)	1652	281	8	2.8	2.2
PTRS-L2	7.4	Very Low	Very Low	7 (<1)	37 (2)	1660	302	7	0.6	2.5
PTRS-MJC	7.3	Low	Medium	22 (2)	100 (8)	1636	314	7	2.7	2.3
PTRS-F18	7.2	Very Low	Medium	9 (<1)	97 (9)	1650	303	7	2.6	2.9
RRS-SL	7.5	Low	Medium	16 (4)	117 (9)	2203	592	6	1.8	2.1
RREC	6.7	Medium	Medium	35 (4)	120 (12)	1299	157	8	7.9	1.7
NEREC	7.1	Optimum	Above Opt	45 (3)	260 (7)	4211	903	8	4.0	3.5
RRS-CL	7.8	Above Opt.	Above Opt	66 (2)	235 (11)	4213	747	10	3.2	2.7

[a] Abbreviations include: NEREC, Northeast Research and Extension Center; PTRS, Pine Tree Research Station; RREC, Rice Research and Extension Center; and RRS, Rohwer Research Station. The letter or letters after the site abbreviation represent the field name.

[b] The soil-test levels are based on the interpretation when the project was initiated (Opt. = Optimum).

[c] The value in parentheses following each P and K mean represents the standard deviation.

Table 3. Expected rice yield response to phosphorus (P), potassium (K), or P and K fertilization compared to a no P and K control at eight research sites established during 2015.

Site[a]	Recommended fertilizer		Expected yield response[b]		Check yield[c]	Yield response to[d]		
	P_2O_5	K_2O	P	K		P only	K only	Recommended[e]
	-------(lb/acre) -----				(bu/acre)	--- [bu/acre yield difference (P-value)]--		
PTRS-I10	60	90	Increase	Increase	197	-9 (0.25)[f]	+17 (0.01)	+9 (0.19)
PTRS-L2	60	120	Increase	Increase	154	-4 (0.27)	+5 (0.13)	+8 (0.03)
PTRS-MJC	60	60	Increase	Increase	135	0 (0.94)	+6 (0.26)[g]	+7 (0.16)
PTRS-F18	60	60	Increase	Increase	216	-2 (0.81)	+1 (0.83)	+8 (0.20)
RRS-SL	60	60	Increase	Increase	164	-3 (0.63)	+4 (0.47)	+1 (0.91)
RREC	60	60	Increase	Increase	151	+1 (0.71)[h]	+1 (0.85)	+2 (0.54)
NEREC	0	0	No Change	No Change	169	-3 (0.66)	-3 (0.60)	NA
RRS-CL	0	0	No Change	No Change	133	+2 (0.79)	0 (0.99)	NA

[a] Abbreviations include: NEREC, Northeast Research and Extension Center; PTRS, Pine Tree Research Station; RREC, Rice Research and Extension Center; RRS, Rohwer Research Station. The letter or letters after the site abbreviation represent the field name.

[b] Expected Response: Increase, soil-test level is Very Low, Low, or Medium; and No Change, soil-test level is Optimum or Above Optimum.

[c] Check yield, the mean yield of rice that received no fertilizer-P or -K.

[d] Yield response: P only, single-degree-of-freedom contrast comparing the yield of rice receiving no fertilizer-P or -K to rice receiving fertilizer-P; K only, single-degree-of-freedom contrast comparing the yield of rice receiving no fertilizer-P or -K to rice receiving the recommended fertilizer-K rate; and Recommended, single-degree-of-freedom contrast comparing the yield of rice receiving no fertilizer-P or K to that of rice fertilized with the recommended rates of both fertilizer-P and -K.

[e] NA indicates that the comparison was not possible. The soil-test recommended no fertilizer-P and K.

[f] Comparison was made using plots that received the same K rate (90 lb K_2O/acre) but different P rates.

[g] Comparison was made using plots that received the same P rate (60 lb P_2O_5/acre) but different K rates.

[h] Comparison was made using plots that received the same K rate (60 lb K_2O/acre) but different P rates.

Table 4. Site responses and accuracy of the soil-test prediction of rice yield response (see Table 3) to phosphorus (P) and potassium (K) fertilization at eight research sites in 2015 as defined by soil-test P (STP) and K (STK) level and the level of significance at which statistical comparisons were made.

Nutrient evaluation[a]	Soil-test level[b]	Soil-test concentration	Total sites	Interpreted at P-value ≤0.05[c]			Interpreted at P-value ≤0.10[c]			Interpreted at P-value ≤0.25[c]		
				I	NC	D	I	NC	D	I	NC	D
		(ppm)		(number of sites[d])								
P-only	VL	<16	2	***0***	2	0	***0***	2	0	***0***	2	0
P-only	L	16-25	3	***0***	3	0	***0***	3	0	***0***	2	1
P-only	M	26-35	1	***0***	1	0	***0***	1	0	***0***	1	0
P-only	O	36-50	1	0	***1***	0	0	***1***	0	0	***1***	0
P-only	AO	>50	1	0	***1***	0	0	***1***	0	0	***1***	0
Overall STP Accuracy (%)[e]				40%			40%			40%		
K-only	VL	<61	1	***0***	1	0	***0***	1	0	***1***	0	0
K-only	L	61-90	1	***1***	0	0	***1***	0	0	***1***	0	0
K-only	M	91-130	4	***0***	4	0	***0***	4	0	***0***	4	0
K-only	O	131-175	0	--	--	--	--	--	--	--	--	--
K-only	AO	>175	2	0	***2***	0	0	***2***	0	0	***2***	0
Overall STK Accuracy (%)[e]				50%			50%			75%		
P&K	Recommended[f]		6	***1***	5	0	***1***	5	0	***4***	2	0
None	Recommended[f]		2	0	***2***	0	0	***2***	0	0	***2***	0
Recommendation Accuracy (%)[e]				58%			58%			83%		

[a] Evaluation of the response of rice fertilized with P-only, K-only, and the Recommended P&K all compared to no fertilizer. "None" is compared to P-only and K-only.

[b] Soil-test level abbreviations: VL, Very Low; L, Low; M, Medium; O, Optimum; AO, Above Optimum.

[c] Abbreviations: I, Increase (yield); NC, No Change in yield; D, Decrease (yield).

[d] Values that are bold and italic represent the anticipated correct yield response to fertilizer applications. Note: small and less frequent yield increases were expected in the M soil-test level compared to the VL and L soil-test levels for both P and K.

[e] Accuracy calculated as the weighted average for the five soil-test levels where the number of sites with the correct outcome (see footnote b) is divided by the number of sites. Overall STK Accuracy was calculated using only four soil-test levels because no site fell within the Optimum soil-test level.

[f] The evaluation of soil-test P and K recommendations regardless of the soil-test level and concentration of each site.

Effects of Three Different Alternate Wetting and Drying Regimes in Rice Cultivation on Yield, Water Use, and Water Use Efficiency in a Clay Soil During a Wet Year

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ABSTRACT

Water available for irrigation is declining in many rice-growing regions around the world. Global populations continue to rise, increasing crop production demand. Rice production systems must face the dilemma of maintaining or increasing yields with less water available to irrigate. Alternate wetting and drying (AWD) has shown to be an effective tool for water conservation in irrigated rice systems. Research on AWD practices is lacking and more information is needed to verify the success of AWD across varying soil types. More work is needed to develop clear recommendations for AWD irrigation practices in Arkansas. In this study we compared the effects of three different AWD regimes and a continuous flood management on rice yields and water-use efficiency (WUE) from a conventional, pure-line cultivar (Roy J) and a hybrid (XL753). The study was located in the northeast corner of the Mississippi delta rice-growing region in Arkansas and results were complicated by a high rainfall pattern in 2015, and unknown factors contributing to low yields even in the conventionally flooded treatments. Even with these complications, the trends in the data indicated that AWD is a feasible water management practice for rice in Arkansas. For both cultivars, all AWD regimes tested in this experiment were associated with a loss in yield, the hybrid cultivar had a higher yield than the conventional cultivar in all treatments. Water-use efficiency for the wettest AWD treatment was higher than the conventional flood treatments and the dryer AWD treatments. Difference in WUE between cultivars was significant and suggests that the hybrid may have a higher WUE than the conventional.

INTRODUCTION

Water available for irrigation is declining in the main crop-growing regions. Irrigation is the largest component of fresh water use (Haddeland et al., 2014). High water use and drought are depleting water available for human use (Schewe et al.,

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2014). The alluvial aquifer in the east-central region of Arkansas is being depleted at unsustainable rates (ANRC, 2012). It has been estimated that 1.8 billion people will be living in regions with absolute water shortages and as much as two-thirds of the global population may be under water stress conditions by 2025 (FAO, 2013). At the same time global populations continue to rise, increasing crop production demand. Ray et al. (2013) estimates that global crop production needs will double by 2050 with an increase of 2.4% annually. Agricultural production systems must face the dilemma of maintaining or increasing yields with less water available to irrigate. Globally, rice production systems account for one-third of the total fresh water use (Bouman, 2009). Although rice and other crops have similar transpiration rates, substantially more water loss is associated with anaerobic rice cultivation practices than aerobic crop production systems due to soil percolation losses and evapotranspiration (Bouman, 2009). Water shortages coupled with the high costs associated with irrigation create the need to research alternate production methods that minimize water use while maximizing/maintaining yields. This can also be referred to as water-use efficiency (WUE) measured as unit of grain per area divided by the volume of water applied per area. Such information will help guide rice producers that face the dilemma of water shortages first hand and provide viable alternative methods to minimize profit losses.

One such method that has been receiving increased attention in recent years is a rice production method referred to as alternate wetting and drying (AWD). Alternate wetting and drying combines the beneficial side effects of anaerobic rice cultivation (nematode and weed control), and aerobic cultivation practices (reduction in water use, grain toxin builds, and greenhouse gas emissions; Price et al., 2013). Alternate wetting and drying has shown to be an effective tool for water conservation in rice-production systems. Zhang et al. (2009) found that AWD can lower water use in rice production by ~35%, while maintaining and even increasing rice yields relative to continual flood methods. Not only does this method reduce water use, but also it has been shown to be very effective in reducing greenhouse gas emissions that result from the brief aerobic periods (Yan et al., 2005; Feng et al., 2013), and at reducing buildup of arsenic in rice grains (Takahashi et al., 2004; Talukder et al., 2012).

In the literature, AWD methods in comparison to anaerobic rice cultivation have a range of results: no difference in yields, yield increases, and yield decreases. Davies et al. (2011) reviewed existing literature and found that mixed results on yield differences is likely dependent on severity of the soil moisture deficit during the dry-down events. This implies that target deficits will vary with differences in soil characteristics. An extensive study has been conducted in the Grand Prairie rice-growing region near Stuttgart, Ark. Linquist et al. (2015) found that in Dewitt silt loam soils, although yields were reduced less than 1% to 13%, the WUE was improved by 18% to 63% and AWD (early season) followed by flooding practices (late season) reduced water use by 18% while maintaining similar yields to that of flooded controls. Research on AWD practices is lacking in other regions of the state and across varying soil types, more work is needed in order to develop clear recommendations for AWD irrigation practices in the state of Arkansas. In this study we compared the effects of three different AWD regimes and

a continuous flood management, on rice yields from a conventional, pure-line cultivar (Roy J) and a hybrid cultivar (XL753) grown on Sharkey silty clay soils in the northeast corner of the Mississippi delta rice-growing region in Arkansas.

PROCEDURE

This study was conducted at the University of Arkansas System Division of Agriculture's Northeast Research and Extension Center near Keiser, Ark., in 2014. The soil type was a Sharkey silty clay with 3% sand, 33.1% silt, and 63.9 % clay (USDA-NRCS, 2013). Saturation, field capacity, and wilting point were calculated using Soil-Plant-Atmosphere-Water (SPAW) software's (USDA-ARS, Washington State University, Pullman, Wash.) soil water characteristics (Saxton et al., 1986) using pesudotransfer functions to determine saturation, field capacity and wilting points of 45.1%, 34.5%, and 13% volumetric soil water content (VWC), respectively. Rice was drill-seeded at a rate of 90 lb/acre for the conventional and 30 lb/acre for the hybrid on 12 June 2015 and plants emerged 19 June 2015. No irrigations were applied until the initial flood 20 July 2015, rainfall was sufficient for stand establishment. Plot sizes were 30 ft × 52 ft (1560 sq ft), separated by dual packed levees to prevent water movement between plots. Plots were planted half with a conventional, pure-line cultivar (Roy J) and half with a hybrid (XL753) of which 260 sq ft of each cultivar in each plot was harvested on 20 October 2015.

The study involved four water management treatments replicated four times in a randomized complete block design. Treatments were: 1) flood (continuously flooded control), 2) AWD/21.6% VWC, 3) AWD/25.4% VWC, and 4) AWD/30.2% VWC. The AWD represents alternate wetting and drying followed by the volumetric soil water content at which subsequent irrigations were triggered. The available water holding capacity of this soil is 21.5% VWC (difference between field capacity and wilting point). The actual deficits the trigger levels represent correspond to 20%, 42.3%, and 60% managed allowable depletions (MAD). These deficits resulted in soil moisture trigger points of 30.2% VWC, 25.4% VWC, and 21.6% VWC respectively.

All treatments were flooded to a 2- to 3-inch depth for 10 days (20 to 30 July) after the preflood nitrogen (N; i.e., urea) fertilizer application of 120 lb N/acre (20 July). In the flooded treatments, this flood depth was maintained throughout the growing season. After the initial 10 day flood, the AWD treatments were allowed to dry until the soil moisture reached the critical VWC triggers for each respective treatment (21.6%, 25.4%, and 30.2% VWC at a soil depth of 2.5 inches) at which time the plots were re-flooded. Critical VWC thresholds were determined using a Dynamax TH300 soil moisture probe. Three measurements were collected from each replication in each treatment if the overall average of all the reps in that treatment reached the threshold or lower; a flood was applied to all plots of that treatment. Water inputs were also measured with 4-inch McCrometer propeller flowmeters in three out of the four replicates to determine the average total water usage for each water management treatment. Weather data was also obtained from the Northeast Research and Extension Center onsite weather sta-

tion. At harvest, grain was harvested, weighed, and moisture readings were obtained for 260 sq ft from each cultivar within each plot using an Almaco SPC40 small plot research combine with 5-foot header width. All yields in bushels per acre (bu/acre) were corrected to 12% moisture.

Data Analysis

All data were analyzed using SYSTAT 13, the treatment and cultivar effects on yield and water-use efficiency were evaluated with an analysis of variance. Normality of all data was confirmed using a Kolmogorov-Smirnov normality test and both models passed homogeneity of variances. Significant treatment effects were further analyzed using a Tukey test method of mean comparison.

In order to compare the differences in yields and relative yields (% relative to the flooded yield average of each respective cultivar) among treatments, an analysis of variance was used with a response variable, yield (bu/acre), and two factors, water treatment (four factor levels: flood, AWD/21.6% VWC, AWD/25.4% VWC, and AWD/30.2% VWC), cultivar (two factor levels: XL753 and Roy J), and a water treatment/cultivar interaction term. Water-use efficiency, bushels per acre-inch of water applied (bu/acre-inch), was calculated for all replicates in each treatment and each cultivar by dividing yield per acre (bu/acre) by the average inches of water applied (acre-inch/acre) for each respective treatment. In order to compare the differences in WUE between water treatments and across cultivars, a balanced analysis of variances with a response variable of WUE and two factors: water treatment (four factor levels: flood, AWD/21.6% VWC, AWD/25.4% VWC, and AWD/30.2% VWC), cultivar (two factor levels, XL753 and Roy J), and a water treatment/cultivar interaction term.

RESULTS AND DISCUSSION

The yields regardless of treatment suffered greatly this season likely due to several factors. First due to the prolonged rain, planting this year was delayed till mid-June and also the plot combine is not a rice machine and the operator expressed that a good percentage of grain was lost through the combine (estimated 20-25%). Onset of irrigation and preflood N fertilizer applications was also delayed due to rain rendering the plots inaccessible as well as warm minimum temperatures could also have contributed to the lower yields this year (Fig. 1). It is likely that other factors (such as possibility of drift) also played into the low yields obtained, however, we have little to no evidence that can help us speculate on other possible factors contributing to the low yields experienced across all water treatments including the conventional flooded treatment. The highest deficit treatment of 60%, AWD/21.6%VWC was far too much of a deficit for use in AWD studies or applications in Sharkey silt clay soils, experiencing on average a 59.6% reduction in yield relative to the average of the conventional flooded treatment, and the average 21.6% VWC treatment yield was 58.4% less than the average flooded yield. This is similar to last years results (Gaspar et al., 2015), that

show the AWD 24%VWC treatment resulted in a 73.5% reduction in yield from the conventional flooded treatment.

Yields

The interaction effect between water treatment and cultivar was not significant for yield ($P = 0.691$) and relative yield ($P = 0.504$). This indicated that cultivar effects on yield and water treatment effects on yield are consistent across all water treatments and cultivars, respectively. Significant effects of water treatment ($P < 0.001$) and cultivar ($P < 0.001$) on yield were observed. The mean comparison for water treatment indicated that the flooded treatment and the AWD/30.2% VWC were significantly similar and had the highest yields (Table 1). The flood treatment average yield (48.8 bu/acre) was 23.4%, 36.7%, and 58.4% greater than the average yield of the AWD/30.2% VWC, AWD/25.4% VWC, and AWD/21.6% VWC treatments, respectively, independent of cultivar. The mean comparison between cultivars indicated that XL753 yielded on average 40.4% more yield than Roy J, irrespective of water treatments.

The relative yield analysis similarly shows that significant effects of water treatment ($P < 0.001$) and cultivar ($P = 0.030$) on yield were observed. The AWD/30.2% VWC, AWD/25.4% VWC, and AWD/21.6% VWC treatment replicates experienced an average reduction in grain production of 24.5%, 38.9%, and 59.6% relative to the flooded treatment average yield, respectively (Table 1).

Water Use Efficiency

The interaction effect between water treatment and cultivar was not significant ($P = 0.154$). This indicated that cultivar effects on WUE and water treatment effects on WUE are consistent across all water treatments and cultivars, respectively. Significant effect of water treatment ($P < 0.001$) on WUE was also observed. The AWD/30.2% VWC (1.77 bu/ac-in) and AWD/25.4% VWC (1.27 bu/ac-in) treatments had the highest grain to water use ratio (Table 2). The data indicate that on average AWD/30.2% VWC yielded 1.1 and 1.25 more bushels of grain/acre-inch of water applied, than AWD/21.6% VWC and flood treatment, respectively. The cultivar difference in WUE was significant ($P < 0.001$), indicating that XL753 on average yielded 0.63 bu of grain more per ac-in of water used than Roy J across all irrigation treatments.

The deviation between cultivar WUE means can be explained from examining the overall mean difference in in WUE between cultivars (Table 2) as well as the least square mean for WUE and yield for each cultivar within each water treatment (data not shown). Despite the fact that both cultivars were planted in each treatment replication and they experienced the same amount of irrigation within each replication, Roy J had consistent lower yields and WUE than XL753 which ultimately lowered the average yield and WUE for each irrigation treatment considerably.

Observational Results

The average water used in each water treatment was greatest for the flood, followed by AWD/21.6% VWC, AWD/25.4% VWC and AWD/30.2% VWC (Table 2). The AWD/21.6% VWC reached trigger point once 54 days after termination of the initial flood, AWD/25.4% VWC reached trigger point once 40 days after termination of the initial flood, and the AWD/30.2% VWC trigger was met twice 32 days after termination of the initial flood, then again 54 days later (Fig. 1). This year had substantial amounts of rain totaling 14.47 inches during the growing season and 9.42 inches during the irrigation period. The dates of the reflood for the treatments was a considerable length of time and is likely due to the high amount of rain during and post initial flood (Fig. 1). Aside from the amount of rainfall this year, the water applied to all treatments was extremely high (Table 2); due to the difficulties establishing the initial flood (Table 2) and in pulling levees in this soil, the levee ditch depth ranged 8 to 9 inches, which could have also contributed to the high water usage. It is also probable that seepage from the levees can also explain the high water use, such was observed in the previous study in 2014 (Gaspar et al., 2015). Bouman and Tuong (2001) found that AWD methods may lead to increased water use due to drying cycles leading to soil shrinkage and cracking. Data like soil moistures and depth data across the levees after a flooding event would be needed to determine if leakage across the levees was occurring. Similarly soil moisture and depth measurement readings across the soil profile could indicate the amount of deep percolation occurring in each plot.

SIGNIFICANCE OF FINDINGS

The flood treatment yielded the most grain relative to the AWD treatments across all cultivars. As the deficit increased so did yield reduction. Overall, XL753 yielded significantly more grain than Roy J (Table 1). On average, WUE was greater for the AWD/32% VWC/ 20% deficit treatment (Table 2) than all other treatments. Difference in WUE averages between cultivars was significant, and suggests that XL753 on average had a 46% higher WUE than Roy J across all irrigation treatments. Although the yields this year were extremely low, the yield reduction was expressed in all irrigation treatments and the trends in the data are very similar to the trends observed in the 2014 season (Gaspar et al., 2015). In this study, AWD had considerable water savings and thus additional research is needed to investigate the potential. Small plot research in this soil type is problematic and further work may need larger plots so that the levee seepage influence is reduced and results will be more relevant to what farmers may experience. No significant difference was found in yield between the 20% and 42% deficit thresholds, so more research is needed to better define allowable depletions for re-flooding. More AWD research is needed to determine applicable thresholds for AWD methods on a wide variety of soil types in order to establish useful guidelines for farmers that wish to implement this water conservation practice.

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Table 1. Yield differences between water treatment (*P* < 0.001) and cultivar (*P* < 0.001) revealed by analysis of variance. Relative yield differences between water treatment (*P* < 0.001) and cultivar (*P* = 0.030) revealed by analysis of variance. Least square means for rice yields and relative yields for water treatment and cultivar, with Tukey method for mean comparison of significant groupings.

Water treatment	Average yield	Relative yield[†]
	(bu/acre)	(% of flooded yield)
Flood	48.8 a[‡]	100 a
20% Deficit/AWD/30.2% VWC[§]	37.4 ab	75.5 ab
42% Deficit/AWD/25.4% VWC	30.9 bc	61.1 bc
60% Deficit/AWD/21.6% VWC	20.3 c	40.4 c
SEM[¶]	4.13	8.41
Cultivar		
XL 753	43.1 a	79.0 a
RoyJ	25.7 b	59.6 b
SEM	2.92	5.95

[†] Relative yield is actual yield divided by the average yields for the flooded treatment reps for each respective cultivar × 100.
[‡] Means within a column followed by different letters are significantly different at the *P* = 0.05 level.
[§] AWD = alternate wetting and drying; VWC = volumetric soil water content.
[¶] SEM = standard error of the mean.

Table 2. Summary of the water usage (applied) and number of irrigations after the initial 10 day flood cycle. Water use efficiency (WUE) differences revealed by analysis of variance for the factor level differences in WUE for water treatment (*P* < 0.001) and cultivar (*P* < 0.001). Least square means for WUE in bushels/acre-inch, for water treatment and cultivar, with Tukey method for mean comparison groupings.

Water treatment	No of refloods post post initial flood	Average total water use	Average water use post initial flood	Water use efficiency
		--------(acre-in./acre)--------		(bu/acre-in.)
20% Deficit AWD/30.2% VWC[†]	2	21.1	10.2	1.77 ab
42% Deficit AWD/25.4% VWC	1	24.3	3.9	1.27 a
60% Deficit AWD/21.6% VWC	1	30.3	4.3	0.67 b
Flood	NA	94.1	68.2	0.52[‡]
SEM[§] = 0.147				
Cultivar				
XL753				1.37 a
RoyJ				0.74 b
SEM = 0.104				

[†] AWD = alternate wetting and drying; VWC = volumetric soil water content.
[‡] Means within a column followed by different letters are significantly different at the *P* = 0.05 level.
[§] SEM = standard error of the mean.

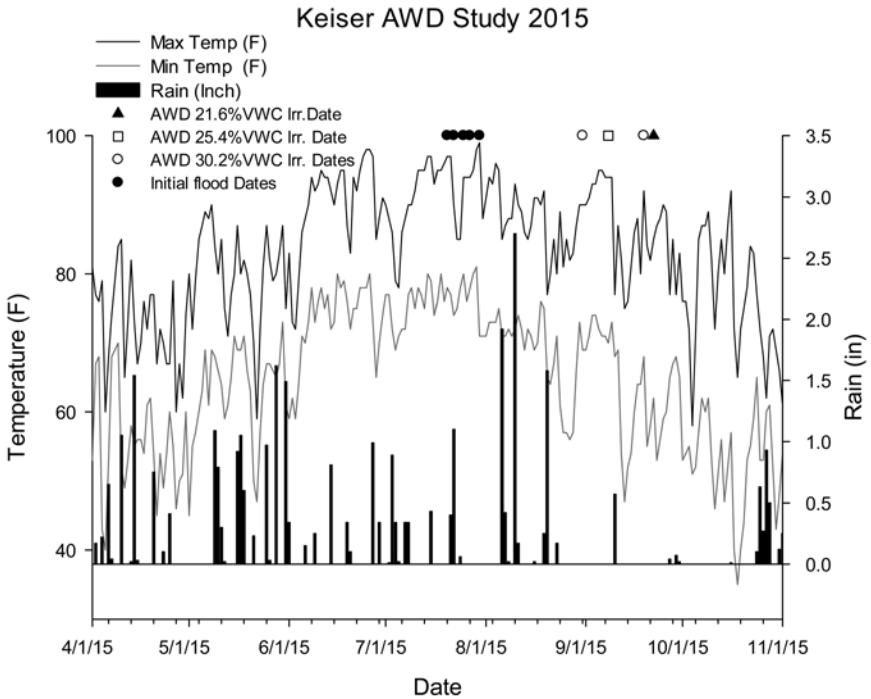

Fig. 1. Minimum and maximum temperature, rainfall, and irrigation dates in the three irrigation treatments [21.6%, 25.4%, and 30.2% volumetric soil water content (VWC)]. AWD = alternate wetting and drying.

Grain Yield Response of Four New Rice Cultivars to Seeding Rate

J.T. Hardke[1], D.L. Frizzell[2], E. Castaneda-Gonzalez[2], T.L. Clayton[3], G.J. Lee[1], and R.J. Norman[4]

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 2015 were CL172, Diamond, LaKast, and Roy J. Each cultivar was seeded at 20, 40, 60, 80, and 100 lb/acre. In accordance with current recommendations and predominate grower practice, all seed received insecticide and fungicide seed treatments. Trials were seeded on research centers/stations at three locations in eastern Arkansas. Stand density and grain yield results were consistent with current seeding rate recommendations of 65 to 70 lb/acre (30 seed/ft^2) under optimum conditions and seeding dates on silt loam soils. Adverse conditions such as late seeding date or clay soil types currently recommend a 20% seeding rate increase (~80 lb/acre; 36 seed/ft^2) compared to a loamy soil and optimum seeding date. Stand density and grain yield at study locations with these conditions also agreed with current recommendations. Care should be taken that without the use of an insecticide seed treatment, stand density and grain yield may be reduced compared to results in this study. Reduced milling yields were only consistently observed at the lowest (20 lb/acre) seeding rate.

INTRODUCTION

The cultivar × seeding rate studies measure the grain yield performance of the new rice (*Oryza sativa* L.) cultivars over a range of seeding rates on representative silt loam and clay soils and determines the proper seeding rate to maximize yield on these soils under climatic conditions that exist in Arkansas. Optimal stand density for cultivars is considered to be 10 to 20 plants/ft^2 (Wilson et al., 2013). The release of new cultivars, combined with changes in production practices including the use of insecticide

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and fungicide seed treatments, requires the continued evaluation of seeding rates for new cultivars to ensure recommendations maximize profit potential for rice growers. The objective of this study was to determine the optimal seeding rate for four new rice cultivars in environments and growing conditions common to Arkansas rice production.

PROCEDURES

The three locations for the 2015 cultivar × seeding rate studies included the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC) near Stuttgart, Ark., on a DeWitt silt loam; the Pine Tree Research Station (PTRS) near Colt, Ark., on a Calloway silt loam; and the Northeast Research and Extension Center (NEREC) near Keiser, Ark., on a Sharkey clay. Studies were seeded at RREC, PTRS, and NEREC on 6 May, 5 June, and 4 May, respectively. All seed was treated with CruiserMaxx® Rice seed treatment. Clearfield CL172, Diamond, LaKast, and Roy J were seeded at each location. Seeding rates evaluated for each cultivar were 20, 40, 60, 80, and 100 lb seed/acre. Actual seeds sown varied according to cultivar with the 60 lb/acre seeding rate equivalent to 27 seed/ft^2 for CL172, 28 seed/ft^2 for Diamond, 25 seed/ft^2 for LaKast, and 27 seed/ft^2 for Roy J. Plots were 9 rows (7-inch spacing) wide and 15 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 6 replications.

Stand density was determined approximately 3 weeks after rice emergence by counting the number of seedlings emerged in 10 row ft of a single row. Nitrogen (N) was applied to studies at the 4- to 5-lf growth stage in a single preflood application of 120 lb N/acre on silt loam soils and 160 lb N/acre on clay soils using urea as the N source. The permanent flood was applied within 2 days of preflood N application and remained flooded until rice reached maturity. At maturity, the center 5 rows of each plot were harvested, the moisture content and weight of grain were determined, and a subsample of harvested grain removed for milling yield determinations. Grain yields were adjusted to 12% moisture and reported on a bushels/acre (bu/acre) basis. 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., Cary, N.C.) with means separated using Fisher's least significant difference test ($P = 0.05$).

RESULTS AND DISCUSSION

Stand density increased as seeding rate increased at all locations (Table 1). A seeding rate of 60 lb/acre reached optimal stand density (~15 plants/ft^2) at RREC which corresponds with current seeding rate recommendations when seeding in the optimal window on a silt loam soil. At PTRS, which was also a silt loam soil but seeded later than the optimal window, an 80 lb/acre seeding rate was needed to achieve optimal stand density. Again, the results at PTRS agree with current recommendations to increase

seeding rate by 20% when seeding after 1 June. On the clay soil at NEREC, optimal stand density was reached at 80 lb/acre, in agreement with current recommendations to increase seeding rate by 20% on a clay soil. Stand densities greater than optimal have the potential to increase the risk of loss rather than profitability. Lodging and disease pressure typically increase when greater than optimal stand densities are reached. It should be noted that the use of an insecticide seed treatment, as in this trial, has been shown to increase stand density by over 10% and increase grain yield by an average of 8 bu/acre (Taillon et al., 2015). Lower stand densities and grain yields may be expected when seeding without the use of insecticide seed treatments.

Seeding rates with above optimum stand densities did not result in greater grain yields compared to the optimal stand density (Table 2). No interaction was observed between cultivar and seeding rate. Grain yields for the seeding rate resulting in optimal stand density were not statistically different than the highest yielding seeding rate for any cultivar or location.

Milling yields were evaluated at the NEREC and PTRS locations (RREC samples could not be evaluated; Table 3). At both locations, the lowest seeding rates resulted in significantly lower head rice and total milled rice yields compared to seeding rates that resulted in optimal stand density.

Comparison of grain yields by converting to percent of optimal yield at each location is provided in Fig. 1. At NEREC, the 80 and 100 lb/acre seeding rates resulted in 96% and 100% optimal grain yields, respectively. At PTRS, the 80 and 100 lb/acre seeding rates produced 99% and 100% of optimal grain yields, respectively. At RREC, the 40, 60, 80, and 100 lb seeding rates produced 96%, 98%, 99%, and 100% of optimal grain yields, respectively. These were the only seeding rates at each location to achieve greater than 95% of optimal grain yield with no adjustment in management practices. When using lower seeding rates or when environmental or soil conditions result in less than desired stand density, other inputs such as N can be managed to recover some lost yield potential (Counce et al., 1992; Wells and Faw 1978).

SIGNIFICANCE OF FINDINGS

The cultivar × seeding rate studies in 2015 agree with previous research that an optimum seeding rate for new rice cultivars is approximately 30 seed/ft^2 (65 to 70 lb/acre). Lower seeding rates risk insufficient stand densities that will be unable to maximize grain yield potential. Currently recommended seeding rate adjustments based on soil type, seeding date, and environmental conditions are in agreement with the findings of this study.

ACKNOWLEDGMENTS

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Table 1. Influence of seeding rate on stand density at three locations during 2015.

	Stand density†		
Seeding rate	**NEREC‡**	**PTRS**	**RREC**
(lb seed/acre)	----------(bu/acre)----------		
20	5.1 e§	5.6 e	6.1 e
40	10.3 d	10.2 d	11.6 d
60	14.2 c	13.4 c	17.4 c
80	18.1 b	18.5 b	22.2 b
100	22.3 a	23.7 a	26.1 a
$LSD_{0.05}$	1.9	2.3	1.4

† Averaged across CL172, Diamond, LaKast, and Roy J cultivars.

‡ NEREC = Northeast Research and Extension Center, Keiser, Ark.; PTRS = Pine Tree Research Station, near Colt, Ark.; and RREC = Rice Research and Extension Center, Stuttgart, Ark.

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

Table 2. Influence of seeding rate on stand density at three locations during 2015.

	Stand density†		
Seeding rate	**NEREC‡**	**PTRS**	**RREC**
(lb seed/acre)	----------(bu/acre)----------		
20	143.1 d§	102.5 d	147.7 c
40	161.6 c	133.5 c	161.8 b
60	168.9 b	143.4 b	165.4 ab
80	177.2 a	151.7 a	165.9 ab
100	183.7 a	153.8 a	168.2 a
$LSD_{0.05}$	7.1	5.9	5.5

† Averaged across CL172, Diamond, LaKast, and Roy J cultivars.

‡ NEREC = Northeast Research and Extension Center, Keiser, Ark.; PTRS = Pine Tree Research Station, near Colt, Ark.; and RREC = Rice Research and Extension Center, Stuttgart, Ark.

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

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Table 3. Influence of seeding rate on rice milling yield at three locations during 2015.

	Milling yield†		
Seeding rate	**NEREC‡**	**PTRS**	**RREC**
(lb seed/acre)	----------(bu/acre)----------		
20	63.9 b – 69.7 b§	58.3 b – 68.3 c	----
40	64.7 a – 70.2 a	58.6 b – 68.9 ab	----
60	64.7 a – 70.2 a	58.4 b – 68.7 bc	----
80	64.9 a – 70.2 a	59.5 ab – 69.3 a	----
100	65.2 a – 70.5 a	60.4 a – 69.0 ab	----
$LSD_{0.05}$	0.6 – 0.4	1.2 – 0.5	----

† Averaged across CL172, Diamond, LaKast, and Roy J cultivars.

‡ NEREC = Northeast Research and Extension Center, Keiser, Ark.; PTRS = Pine Tree Research Station, near Colt, Ark.; and RREC = Rice Research and Extension Center, Stuttgart, Ark.

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

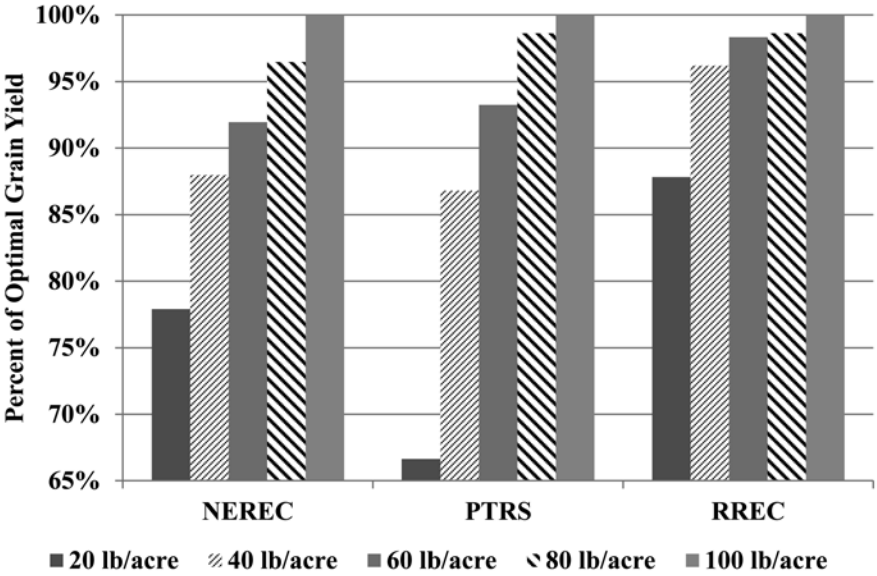

Fig. 1. Influence of seeding rate on rice grain yield at the Northeast Research and Extension Center (NEREC), Pine Tree Research Station (PTRS), and Rice Research and Extension Center (RREC) during 2015. Percent of optimal grain yield calculated based on the highest grain yield at each location equivalent to 100% optimal grain yield.

Arkansas Rice Performance Trials, 2013-2015

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ABSTRACT

The Arkansas Rice Performance Trials (ARPT) 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 seeded 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 five locations during 2015. Averaged across locations, grain yields were highest during 2015 for the commercial cultivars XL753, XL760, CLXL729, CLXL745, and Diamond. Cultivars with the highest overall milling yields during 2015 included: Mermentau, Antonio, CL111, CL153, and CL163

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

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factors as grain and milling yields, kernel size, maturity, lodging resistance, plant height, and disease susceptibility.

The Arkansas Rice Performance Trials (ARPT) 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 five locations for the 2015 ARPTs included the University of Arkansas System Division of Ariculture's Rice Research and Extension Center (RREC) near Stuttgart, Ark.; the Pine Tree Research Station (PTRS) near Colt, Ark.; the Northeast Research and Extension Center (NEREC) near Keiser, Ark.; the Trey Bowers farm in Clay County (CLAY); and the Brandon Truax farm in Desha County (DESHA). Ninety entries, including established cultivars and promising breeding lines, were grown across a range of maturities.

The studies were seeded at RREC, PTRS, NEREC, CLAY, and DESHA on 22 April, 5 June, 4 May, 30 April, and 5 May, respectively. Pure-line cultivars (varieties) were drill-seeded at a rate of 30 seed/ft^2 in plots 8 rows (7-inch spacing) wide and 15 ft in length. Hybrid cultivars were drill-seeded into the same plot configuration using a seeding rate of 13 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-lf growth stage in a single preflood application of 120 lb N/acre on silt loam soils and 150 lb N/acre 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 five 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/acre (bu/acre) basis. 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. Each location of the study was arranged in a randomized complete block design with four replications.

RESULTS AND DISCUSSION

The 3-year average of agronomic traits, grain yields, and milling yields of selected cultivars evaluated during 2013-2015 are listed in Table 1. The top yielding entries, averaged across three study years, include: XL753, Diamond, Caffey, and Titan with

grain yields of 239, 210, 204, and 204 bu/acre, respectively. In regard to milling yield (%HR - %TR), Antonio, CL151, Mermentau, CL111, CL163, and Roy J had the highest overall average milling yields from 2013-2015.

Selected agronomic traits, grain yield, and milling yields from the 2015 ARPT are shown in Table 2. Mean grain yield across all locations and cultivars was 167 bu/acre. Cultivar XL753 was the only commercial cultivar to maintain a grain yield above 200 bu/acre at all locations, although XL760 did have a mean grain yield >200 bu/acre over the five locations. Other notable cultivars with high mean grain yields over the five locations in 2015 included CLXL729, CLXL745, Diamond, Caffey, and Jupiter. Milling yield, averaged across locations and cultivars, was 59-69 (%HR - %TR) during 2015. The long-grain cultivars Mermentau, Antonio, CL111, CL153, and CL163 had the highest milling yields of all commercial entries, averaging 63-69, 62-70, 62-70, 62-70, and 62-69, respectively, across all 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, 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.

SIGNIFICANCE OF FINDINGS

Data from this study will assist rice producers in selecting cultivars suitable to the wide range of growing conditions, yield goals, and disease pressure found throughout Arkansas.

ACKNOWLEDGMENTS

The Arkansas Rice Performance Trials are supported through grower check-off funds administered by the Arkansas Rice Research and Promotion Board and the University of Arkansas System Division of Agriculture. We wish to thank the following people for their dedication to making the ARPT possible each year: Chuck Pipkins, Tara Clayton, and Shawn Clark.

Table 1. Results of the Arkansas Rice Performance Trials

Cultivar	Grain length[a]	Straw strength rating[b]	50% heading[c]	Plant height	Test weight	Milled kernel weight[d]	Chalky kernels[d]
			(days)	(in.)	(lb/bu)	(mg)	(%)
Antonio	L	2.0	80	37	43.6	20.3	1.94
Caffey	M	2.2	82	38	43.1	23.5	1.47
CL111	L	1.6	80	38	43.1	19.6	2.88
CL151	L	1.6	80	38	43.1	19.6	2.88
CL163	L	1.8	84	38	44.2	--	--
CL271	M	1.6	84	38	44.0	--	--
CLXL729	L	3.9	80	43	43.7	20.5	2.19
CLXL745	L	4.1	77	44	44.0	22.2	1.93
Diamond	L	1.8	81	40	43.0	21.5	1.40
Jupiter	M	2.9	83	37	42.2	21.0	2.38
LaKast	L	2.5	80	41	43.4	21.6	1.04
Mermentau	L	1.4	80	37	43.3	19.6	1.88
MM14	M	--	83	35	44.5	--	--
Roy J	L	1.0	85	41	42.7	21.0	1.13
Taggart	L	1.8	84	43	43.0	22.5	1.02
Titan	M	2.3	77	38	43.0	22.8	2.47
Wells	L	2.1	82	40	43.2	21.4	1.37
XL753	L	2.5	78	43	43.8	21.0	2.13
Mean		2.2	81	39.3	43.4	21.3	1.76

[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 (2012-2014 data due to no lodging in 2015).
[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, 2012-2014. Based on weight of 1000 kernels.

averaged across the three-year period of 2013-2015.

Milling yield by year				Grain yield by year			
2013	**2014**	**2015**	**Mean**	**2013**	**2014**	**2015**	**Mean**
------- (% head rice - % total rice) ------				**----------(bu/acre) ----------**			
65-70	66-72	62-70	64-71	191	174	141	169
58-67	57-69	56-68	57-68	217	216	179	204
65-70	65-71	61-70	64-70	189	202	166	186
65-70	65-71	61-70	64-70	189	202	166	186
--	63-70	61-70	62-70	--	186	151	168
--	58-70	52-68	55-69	--	190	166	178
62-69	61-70	59-69	61-69	205	202	194	200
61-69	61-71	58-69	60-70	179	203	187	189
62-68	61-69	60-69	61-69	226	218	186	210
61-66	59-68	61-68	60-67	200	213	176	196
63-70	62-71	56-68	60-70	203	202	162	189
65-69	66-71	63-69	65-70	190	181	161	177
--	52-69	61-69	56-69	--	196	155	176
63-70	62-70	61-70	62-70	210	207	169	195
62-69	60-70	58-70	60-70	205	200	167	191
58-67	55-69	56-68	56-68	212	235	165	204
62-70	57-70	57-70	59-70	196	192	161	183
60-70	57-71	54-69	57-70	245	259	212	239
60-71	63-69	62-70	62-70	203	203	169	190

Table 2. Results of the Arkansas Rice Performance Trials at five locations during 2015.

Cultivar	Grain length[a]	Straw strength[b]	50% heading[c]	Plant height	Test weight	Milling yield[d]	Grain yield by location and seeding date					
							CLAY 30 April	DESHA 5 May	NEREC 4 May	PTRS 5 June	RREC 22 April	Mean
		(rating)	(days)	(in.)	(lb/bu)	(%HR-%TR)	(bu/acre)					
Antonio	L	--	75	37	46.9	62-70	162	139	166	122	118	141
Caffey	M	--	79	37	46.0	57-68	194	139	206	176	182	179
CL111	L	--	74	39	47.6	62-70	160	141	147	139	133	144
CL151	L	--	74	38	46.5	61-70	182	164	188	161	136	166
CL153	L	--	77	37	46.8	62-70	166	144	185	150	124	154
CL163	L	--	79	37	46.3	62-69	133	149	180	148	145	151
CL172	L	--	77	35	46.1	61-70	156	130	165	128	133	142
CL271	M	--	79	38	45.9	58-69	177	138	198	177	140	166
CL272	M	--	77	37	46.5	52-68	171	132	206	158	141	162
CLXL729	L	--	74	45	47.7	59-69	194	165	207	211	195	194
CLXL745	L	--	72	45	47.6	58-69	194	167	185	189	198	187
Diamond	L	--	77	39	46.1	60-69	189	169	232	171	172	186
Jupiter	M	--	79	36	45.0	61-68	183	137	201	164	194	176
LaKast	L	--	74	41	47.4	56-68	178	150	184	148	149	162
Mermentau	L	--	76	37	46.5	63-69	174	167	187	140	137	161
MM14	M	--	77	33	46.5	61-69	173	135	169	134	166	155
Roy J	L	--	81	39	45.4	61-70	182	149	195	170	146	169
Taggart	L	--	80	41	46.0	59-70	182	157	194	159	143	167
Titan	M	--	73	36	46.1	56-68	180	129	200	142	173	165
Wells	L	--	78	39	46.5	57-70	179	149	182	165	131	161
XL753	L	--	73	46	47.7	54-69	219	202	218	209	210	212
XL760	L	--	77	45	46.7	59-69	211	187	226	210	204	207
MSX4077	L	--	77	39	46.1	60-69	189	169	232	171	172	186
Mean		--	77	39	46.5	59-69	177	151	191	160	157	167

[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 (no lodging in 2015).
[c] Number of days from plant emergence until 50% of the panicles are visibly emerging from the boot.
[d] % HR - % TR = percent head rice - percent total rice.

Table 3. Rice cultivar reactions[a] to diseases (2015).

Cultivar	Sheath blight	Blast	Straight-head	Bacterial panicle blight	Narrow brown leaf spot	Stem rot	Kernel smut	False smut	Lodging	Black sheath rot
Antonio	S	S	--	MS	MS	S	S	MS	MS	--
Caffey	MS	MR	--	S	R	--	--	MS	--	--
Cheniere	S	VS	VS	VS	S	S	S	S	MR	MS
CL111	VS	MS	S	VS	VS	VS	S	S	MS	S
CL151	S	VS	VS	VS	S	VS	S	S	MS	S
CL152	S	VS	S	S	MR	--	VS	S	--	--
CL153	S	MS	--	--	--	--	S	S	--	--
CL163	S	S	--	MS	--	--	MS	--	--	--
CL172	MS	MS	--	MS	--	--	MS	S	--	--
CL271	S	MR	--	MS	MR	--	MS	--	--	S
CL272	S	S	--	VS	--	--	MS	--	--	--
CLXL729	MS	R	MS	MR	MS	S	MS	S	S	S
CLXL745	S	R	R	MR	MS	S	MS	S	S	S
CLXP756	MS	--	--	--	--	--	--	S	--	S
Cocodrie	S	S	VS	S	S	VS	S	S	MR	S
Della-2	S	R	--	S	MS	--	--	--	--	--
Francis	MS	VS	MR	VS	S	S	VS	S	MS	S
Jazzman	MS	S	S	S	S	S	MS	S	MS	MS
Jazzman-2	VS	S	--	VS	MR	--	S	S	--	--
Jupiter	S	S	S	MR	MS	VS	MS	MS	MS	MR
LaKast	S	S	MS	S	MS	S	S	S	MS	MS
Mermentau	S	S	VS	MS	MS	--	S	S	MS	--
MM14	--	--	--	S	--	--	--	S	--	--
Rex	S	S	S	S	MS	S	S	S	MR	S
Roy J	MS	S	S	S	MR	S	VS	S	MR	MS
XL723	MS	R	S	MR	MS	S	MS	S	MS	S
XL753	MS	R	MS	MR	--	--	MS	S	--	S
XL760	MS	--	--	--	--	--	MS	VS	--	--
Taggart	MS	MS	R	MS	MS	S	S	S	MS	MS

continued

Table 3. Continued.

Cultivar	Sheath blight	Blast	Straight-head	Bacterial panicle blight	Narrow brown leaf spot	Stem rot	Kernel smut	False smut	Lodging	Black sheath rot
Titan	S	MS	--	S	--	--	S	MS	--	--
Wells	S	S	S	S	S	VS	S	S	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 in grower fields across Arkansas and other rice states in southern U.S.A. In general, these ratings represent expected cultivar reactions to disease under conditions that most favor severe disease development. Table prepared by Y. Wamishe, Assistant Professor/Extension Plant Pathologist

Methane Emissions from Direct-Seeded, Delayed-Flood Rice Production as Influenced by Cultivar and Water Management

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ABSTRACT

Methane (CH_4) emissions from direct-seeded, delayed-flood rice (*Oryza sativa* L.) production are a source of concern in the environmental and agricultural communities. Addressing both communities' needs requires the use of new cultivars and appropriately timed production practices to achieve the desired goal of determining methods to reduced CH_4 emissions without decreasing yields or milling quality. The objective of this study was to evaluate the effects of rice cultivar (i.e., conventional, pure-line rice cultivar LaKast and hybrid rice cultivar RiceTec XL753) and water management (i.e., full-season flood and midseason drain) on CH_4 emissions from a silt-loam soil at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center, near Stuttgart, Ark. Vented, non-flow-through, non-steady-state chambers were used to collect gas samples for measurement of CH_4 fluxes. Methane fluxes were calculated according to changes in concentration in the chamber headspace over the 60-min sampling interval. The hybrid with the full-season flood produced the numerically largest yield (249 bu/acre, 12,560 kg/ha) and the numerically largest CH_4 emissions (79.1 kg CH_4-C/ha/season). The numerically lowest CH_4 emissions (28.9 kg CH_4-C/ha/season) came from the hybrid with the midseason drain, which had a yield of 227 bu/acre (11,451 kg/ha). The proper combination of cultivar selection and water management can help reduce CH_4 emissions from rice production on silt-loam soils.

INTRODUCTION

Total United States greenhouse gas (GHG) emissions increased by 8.4% from 1990 to 2011, with a 1.6% decrease from 2010 to 2011, followed by a 2% increase in 2012 to a total 2013 U.S. GHG emissions of 6673 million metric tons of carbon diox-

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ide CO_2 equivalent [United States Environmental Protection Agency (USEPA), 2014]. However, over the last 250 years, the concentration of methane (CH_4) in the atmosphere has increased by 158% (IPCC, 2007). The overall amount of CO_2 emissions from 1990 to 2011 increased by 504 Tg of CO_2 equivalent, while emissions of CH_4 have decreased by 57.2 Tg of CO_2 equivalent (IPCC, 2014). Methane is a potent GHG that is produced under anoxic conditions when organic matter is converted to CH_4 by a class of microorganisms known as methanogens. Several biochemical processes exist where carbon (C) is reduced to CH_4, thus releasing energy for metabolic processes. As of 2011, CH_4 emissions from rice (*Oryza sativa* L.) cultivation represented 1.1 % of overall U.S. CH_4 production (IPCC, 2014). The main source of CH_4 in the soil column is in the topsoil, where >99% of the total soil-produced CH_4 is emitted (Mitra et al., 2002).

Management practices under which rice is cultivated are one of the most important factors affecting CH_4 emissions. Hybrid cultivars have shown a decreased amount of CH_4 emissions compared to conventional cultivars (Rogers et al., 2014). Rice in the U.S. is generally grown under continuously flooded conditions throughout the growing season. Midseason drainage does not occur except by accident or when controlling for straighthead, which is a disorder that causes sterility of the spikelets and reduces yield (IPCC, 2014). To reduce CH_4 emissions from flooded rice, field management practices must be developed that will reduce CH_4 emissions without decreasing yields or milling quality (Lindau et al., 1993). The objective of this study was to evaluate the effects of rice cultivar (i.e., conventional, pure-line rice cultivar LaKast and hybrid rice cultivar RiceTec XL753) and water management (i.e., full-season flood and midseason drain) on CH_4 emissions from a silt-loam soil at the Rice Research and Extension Center, near Stuttgart, Ark.

MATERIAL AND METHODS

Field research conducted in 2015 was similar to that conducted by Rogers et al. (2014) at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center near Stuttgart, Ark. (34°27'54.5" N, 91°25'8.6" W). The study area consisted of a total of 16 field plots, 5-ft 5-in (1.6-m) wide × 16-ft 5-in (5-m) long, with 9 rice of rows and 7-in (18-cm) row spacing. Plots were arranged in 2 blocks with 8 plots per block. Rice was seeded on 6 May 2015. The conventional rice cultivar LaKast and the hybrid rice cultivar RiceTec XL753 were seeded. The flood was established on 15 June 2015. Optimal N fertilization was used for both cultivars. The conventional cultivar received 104 lb N/acre (117 kg/ha) 24 hr before the flood was established, and 45 lb N/acre (50 kg/ha) at 0.5-in. internode elongation. The hybrid cultivar XL753 received 120 lb N/acre (134 kg/ha) preflood, and 30 lb N/acre (33 kg/ha) at the boot stage, after planting, and before the flood was established. After planting and before flooding, a boardwalk system was constructed throughout the plots to reduce disturbances to the plants and allow easier access to the plots during the growing season.

Prior to flood establishment, two soil cores, 2-in. (4.8-cm) in diameter were collected from the top 4-in. (10-cm) in each plot for a total of 32 cores collected from the entire study area. All soil samples were dried at 158 °F (70 °C) for 72 h, crushed, and sieved through a 2-mm metal mesh screen for soil property determinations. Sixteen soil

samples were used for particle-size analyses, where the average particle-size distribution in the top 10 cm was 21% sand, 72% silt, and 7% clay, which results in a silt-loam soil texture (Table 1). The other 16 soil samples collected were analyzed by inductively coupled, atomic emission spectrometry (Spectro Arcos, Spectro Analytical Instruments, Kleve, Germany) using a 1:10 soil mass to solution extractant ratio as used by Tucker (1992) for Mehlich-3 extractable nutrients (P, K, Ca, Mg, S, Na, Fe, Mn, Zn, Cu, and B; Mehlich, 1984). Total carbon (TC) and total nitrogen (TN) concentrations were measured by high-temperature combustion with a VarioMaxCN analyzer (Elementar Americas, Inc., Mt. Laurel, N.J.). Soil organic matter (SOM) concentration was determined by weight-loss-on-ignition after 2 h at 360 °C. Soil pH and electrical conductivity (EC) were analyzed potentiometrically in a 1:2 (m/v) soil/water suspension.

Schedule 40 polyvinyl chloride (PVC) was used in the construction of cylindrical base collars that measured 12-in. (30-cm) in diameter × 12-in. (30-cm) tall, and were inserted to a depth of approximately 4-in. (10-cm). Vented, non-flow-through, non-steady-state chambers (Livingston and Hutchinson, 1995) were used for the collection of gas samples for the determination of CH_4 fluxes. Seven days after the last gas sampling, all aboveground dry matter was collected from the interior of the chamber. Using a flame ionization detector (250 °C) equipped with a gas chromatograph (Model 6890-N; Agilent Technologies, Santa Clara, Calif.) with a 0.53-mm-diameter by 30-m-HP-Plot-Q capillary column (Agilent Technologies, Santa Clara, Calif.), gas samples were analyzed for CH_4 concentrations within 48 h of collection. Methane fluxes were calculated according to changes in concentrations in the chamber headspace over a 60-min sampling interval following procedures outlined by (Rogers et al., 2013). To determine the change in concentration over time, measured concentrations (mL L^{-1}; y axis) were regressed against time (min; x axis) of sample extraction (i.e., 0, 20, 40, and 60 min). Means of CH_4 emissions, rice yields, and emissions per unit grain yield were calculated and presented.

RESULTS AND DISCUSSION

Initial Soil Properties

Initial soil properties were relatively uniform among plots throughout the study area, as indicated by the relatively low standard errors associated with soil property means reported in Table 1. Most initial soil properties were within recommended ranges for optimal rice production on a silt loam soil (Table 1). Extractable soil K and Zn concentrations were within recommended optimum levels at 167 and 7.7 ppm (mg/kg), respectively, and extractable soil P was above optimum levels at 71 ppm (mg/kg) (Table 1) for rice production on a silt loam soil according to the University of Arkansas System Division of Agriculture Cooperative Extension Service (Norman et al., 2013).

Methane Fluxes and Emission, and Rice Yields

Methane fluxes from the hybrid XL753 with the midseason drain were comparable to that from the full-season flood before the drain occurred and the flood was

reestablished, while fluxes from the drained area were reduced and remained lower than that from the full-season flood after flood reestablishment (Fig. 1). Regardless of water management, the conventional cultivar had a similar temporal trend of CH_4 fluxes, but overall had a numerically lower yield than the hybrid. Methane fluxes peaked just after 50% heading and exhibited a small increase just after the end-of-season drain, which was consistent with previous reports (Rogers et al., 2014).

The numerically lowest CH_4 emissions of 28.9 kg CH_4-C/ha/season came from the hybrid with the midseason drain, which had a yield of 227 bu/acre (11,451 kg/ha) (Table 2). Methane fluxes for the conventional rice cultivar LaKast had a yield of 205 bu/acre (10,341 kg/ha) and emissions of 76.4 kg CH_4-C/ha/season for the full-season flood, and a yield of 198 bu/acre (9988 kg/ha) and emissions of 56.6 kg CH_4-C/ha/season for the midseason drain.

The numerically largest-yielding cultivar-water-management treatment combination was the hybrid with the full-season flood at 249 bu/acre (12,560 kg/ha), but this treatment combination also had numerically the largest CH_4 release at 79.1 kg CH_4-C/ha/season (Table 2). The hybrid with the midseason drain had numerically the greatest C efficiency at 0.003 kg CH_4-C/kg grain, while the lowest numerical efficiency was from the conventional cultivar full-season flood treatment combination at 0.007 kg CH_4-C/kg grain. The hybrid midseason drain produced 65.7% less CH_4 emissions, but only a 9.8% reduction in grain yield compared to the hybrid full-season flood treatment combination. The conventional cultivar midseason flood had 23.2% lower CH_4 emissions, but only 3.5% lower grain yield compared to the conventional cultivar full-season flood treatment combination.

SIGNIFICANCE OF FINDINGS

The midseason drain numerically decreased the amount of CH_4 produced in both conventional and hybrid rice cultivars with only slight yield reductions compared to the full-season flood. Methane production and mitigation in direct-seeded, delayed-flood rice production are important not only because of the climate-change impact, but also as a way to potentially conserve organic matter in the soil if CH_4 emissions are reduced. This study showed that, numerically, midseason draining combined with a hybrid rice cultivar can reduce CH_4 emissions compared to a conventional cultivar grown with a full-season flood. Continued investigation is needed to better understand the relationships among rice cultivars (i.e., conventional vs hybrid), water management strategies, and CH_4 emissions from silt-loam soils.

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Table 1. Mean soil physical and chemical properties (n = 16) before flood establishment from the top 10 cm of a Dewitt silt loam located at the Rice Research and Extension Center near Stuttgart, Ark., during the 2015 growing season.

Soil property	Mean (± Standard Error)
Sand (%)	21.1 (0.17)
Silt (%)	71.7 (0.21)
Clay (%)	7.2 (0.21)
pH	6.6 (0.05)
Electrical conductivity (µmhos/cm)	229 (9.4)
Mehlich-3 Extractable Nutrients (ppm, mg/kg)	
P	71 (2.5)
K	167 (5.5)
Ca	1159 (15.1)
Mg	116 (1.2)
S	10.5 (0.4)
Na	108 (4.1)
Fe	468 (7.4)
Mn	212 (4.7)
Zn	7.7 (0.9)
Cu	0.97 (0.04)
B	0.73 (0.01)
Total N (%)	0.09 (0.00)
Total C (%)	0.76 (0.01)
Soil organic matter (%)	1.53 (0.01)

Table 2. Summary of average methane (CH_4) emissions, rice yield, and methane emissions per unit grain yield by rice cultivar/water management treatment combination.

Cultivar/water management combination	Methane emission	Rice yield	Rice yield	Emissions:yield ratio
	(kg CH_4-C/ha/season)	(bu/acre)	(kg/ha)	(kg CH_4-C/kg grain)
LaKast/midseason drain	56.6	198	9988	0.006
XL753/midseason drain	28.9	227	11451	0.003
LaKast/full-season flood	76.4	205	10341	0.007
XL753/full-season flood	79.1	249	12560	0.006

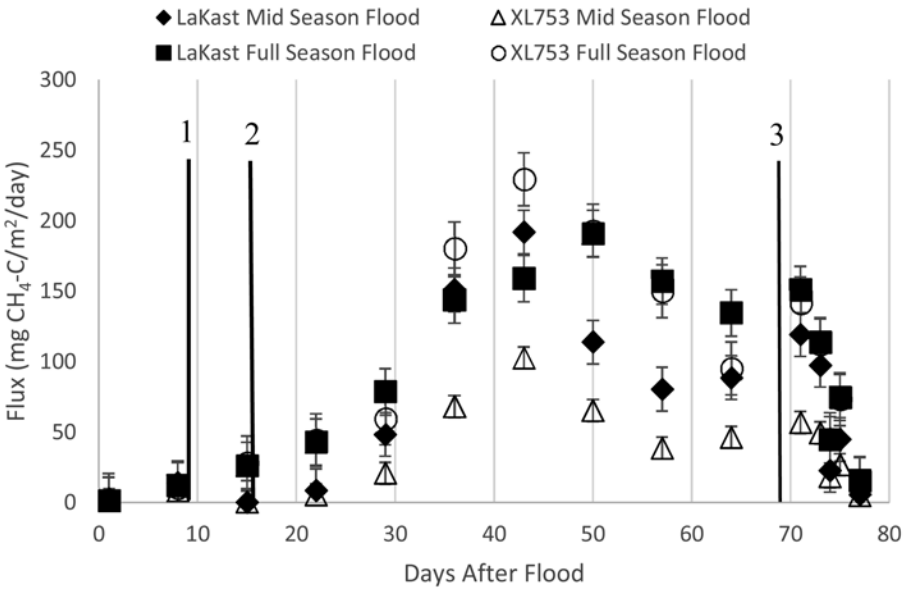

Fig. 1. Growing-season methane (CH_4) fluxes or the treatment combinations of cultivar (conventional LaKast or hybrid XL753) and water management (full-season flood or midseason drain). The thick vertical lines indicate the timing of (1) flood release for the midseason drain, (2) flood reestablishment after the midseason drain, and (3) flood release from all plots prior to harvest. Standard error bars accompany treatment means (n = 4).

Utilization of On-Farm Testing to Evaluate Rice Cultivars, 2015

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ABSTRACT

On-farm testing provides researchers with the best opportunity to evaluate the performance of cultivars under diverse production conditions. The Producer Rice Evaluation Program (PREP) utilizes studies in commercial rice fields throughout the state to evaluate experimental lines and commercial cultivars for disease, lodging, grain yield potential, and milling quality in diverse growing conditions, soil types and farming practices. For producers, knowing the optimum cultivar for each field is their biggest and most important tool. On-farm testing can indicate which cultivars are suited for a particular growing situation. Field studies were located in Chicot, Craighead, Greene, Lincoln, Lonoke, Prairie, and Woodruff counties during the 2015 growing season. Nineteen cultivars were selected for evaluation in the on-farm tests. The average grain yield across all locations was 185 bu/acre and the mean milling yield (%HR-%TR) was 59-69. The cultivars with the highest grain yields averaged across locations were XL753 and CLXL729 followed by XL760, CLXL745, and LaKast.

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 DD50 Program thresholds. Many factors can influence grain yield potential including: 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 fungicides (when necessary based

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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 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 information obtained from field research coupled with 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 field conditions, 2) to monitor disease pressure in the different regions of Arkansas, and 3) to evaluate the performance of rice cultivars under conditions not commonly observed on experiment stations.

PROCEDURES

Field studies were located in Chicot, Craighead, Greene, Lincoln, Lonoke, Prairie, and Woodruff counties during the 2015 growing season. Nineteen cultivars were selected for evaluation in the on-farm tests. Non-Clearfield entries evaluated during 2015 included Diamond, Jupiter, LaKast, Mermentau, Roy J, Taggart, Titan, a Mississippi State University experimental line (MSX4077), and the RiceTec hybrids XL753 and XL760. Clearfield entries included CL111, CL151, CL153, CL163, CL172, CL271, CL272, and the RiceTec hybrids CLXL729 and CLXL745.

Plots were 8 rows (7-in. spacing) wide and 15-ft in length arranged in a randomized complete block design with four replications. Pure-line cultivars (varieties) were seeded at a rate of approximately 30 seed/ft^2 while hybrids were seeded at a rate of approximately 14 seed/ft^2. Trials were seeded on 8 April (Lincoln and Woodruff), 9 April (Prairie), 21 April (Lonoke), 27 April (Craighead), 30 April (Greene), and 5 May (Chicot). Since these experiments contain both Clearfield and non-Clearfield entries, all plots were managed as non-Clearfield cultivars.

Plots 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. Plots

were inspected periodically and rated for disease. Percent lodging notes were taken immediately prior to harvest. At maturity, the center five 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/acre (bu/acre) basis. 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., Cary, 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 2015 growing season; a summary of the results by county and corresponding date of seeding is presented in Table 1. The average grain yield across all locations was 185 bu/acre. The cultivars with the highest grain yields averaged across locations were XL753 and CLXL729 followed by XL760, CLXL745, and LaKast. In the Chicot Co. trial grain yield averaged 185 bu/acre and the highest-yielding entries were XL753, XL760, CLXL729, and CLXL745 (Table 2). The mean milling yield for Chicot Co. was 67-72. In the Craighead Co. trial, grain yield for the location averaged 164 bu/acre with a mean milling yield of 66-71 (Table 3). The highest yielding cultivars in Craighead Co. were CLXL729, XL753, XL760, and CLXL745. In Greene Co., XL753 and CLXL729 were the highest-yielding cultivars and the location averaged 180 bu/acre with a mean milling yield of 67-71 (Table 4). The Lincoln Co. trial was the highest-yielding location during 2015 with an average yield of 219 bu/acre and a mean milling yield of 61-66 (Table 5). The highest yielding cultivars were CLXL729 and CLXL745 in Lincoln Co. In Lonoke Co., XL760 and XL753 were the highest yielding cultivars (Table 6). The average grain yield in Lonoke Co. was 204 bu/acre with a mean milling yield of 57-67 (Table 6). Rice Tec XL753, Roy J, and Diamond were the highest yielding cultivars in Prairie Co. The cultivars in Prairie Co had an average yield of 184 bu/acre and a mean milling yield of 44-67 (Table 7). The highest yielding cultivars in the Woodruff Co. trial were XL753, CLXL745, CL111, and LaKast (Table 8). Woodruff Co. had the lowest overall yield of all the counties at 158 bu/acre with a mean milling yield of 50-68. Unfortunately, the Woodruff Co. location had issues with hydrogen sulfide toxicity affecting plant development and grain yield. 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 by University of Arkansas System Division of Agriculture for use by growers (Table 9). This is particularly true for minor diseases 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.

SIGNIFICANCE OF FINDINGS

The 2015 Producer Rice Evaluation Program (PREP) 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 2016.

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Table 1. Results of the Producer Rice Evaluation Program at seven locations during 2015.

Cultivar	Grain length[a]	Lodging	Moisture	Test weight	Milling yield[b]	Grain yield by location and planting date: Chicot 5/5	Craighead 4/27	Greene 4/30	Lincoln 4/8	Lonoke 4/21	Prairie 4/9	Woodruff 4/8	Mean
		--------- (%) ---------		(lb/bu)	(%HR-%TR)	----------(bu/acre)----------							
CL111	L	0.0	14.3	43.4	60-70	170	141	178	223	194	145	172	175
CL151	L	2.7	14.9	43.2	60-70	165	169	192	225	185	153	147	177
CL153	L	0.0	15.1	42.9	61-70	172	166	173	234	195	190	143	182
CL163	L	0.9	15.5	41.7	62-69	166	103	137	216	190	196	161	167
CL172	L	0.2	15.9	43.2	61-69	151	150	133	197	170	184	151	162
CL271	M	0.5	15.5	43.6	57-69	163	165	157	189	175	176	162	169
CL272	M	0.2	15.5	44.8	54-69	174	164	170	210	193	177	161	178
CLXL729	L	3.0	14.3	40.2	58-69	231	206	243	287	248	192	161	224
CLXL745	L	9.6	14.1	40.3	60-70	212	190	229	268	243	152	174	210
Diamond	L	2.1	16.1	43.8	58-69	206	187	195	205	219	204	165	197
Jupiter	M	0.0	18.0	46.9	61-68	152	141	142	196	181	175	139	161
LaKast	L	0.2	14.5	43.8	57-69	208	182	193	230	218	193	169	199
Mermentau	L	0.0	16.0	42.8	62-69	178	155	163	196	183	170	141	169
Roy J	L	0.9	17.5	43.2	59-70	171	177	151	192	205	209	142	180
Taggart	L	0.0	16.4	44.7	57-69	181	175	160	202	186	193	138	176
Titan	M	0.7	16.2	46.4	52-68	157	149	197	222	199	191	167	183
XL753	L	3.8	14.0	41.4	57-70	245	198	244	257	250	227	193	231
XL760	L	2.1	15.9	40.4	59-69	239	197	202	252	261	202	154	215
MSX4077	L	0.5	15.2	44.7	60-69	170	95	164	180	188	176	154	161
Mean	--	1.4	15.5	43.2	59-69	185	164	180	220	204	184	158	185
$LSD_{0.05}$[c]	--	3.3	0.4	0.7	1.9-0.5	11.8	12.9	14.8	10.9	12.4	22.3	NS	7.9

[a] Grain length: L = long-grain; M = medium-grain.
[b] %HR - %TR = percent head rice - percent total white rice.
[c] LSD = least significant difference.

Table 2. Results of Chicot Co. Producer Rice Evaluation Program Trial during 2015.

Cultivar	Grain length[a]	Lodging	Moisture	Test weight	Grain yield	Milling yield[b]
		---------- (%) ----------		(lb/bu)	(bu/acre)	(%HR-%TR)
CL111	L	0.0	14.8	42.3	170	67-72
CL151	L	0.0	15.9	42.0	165	67-72
CL153	L	0.0	17.2	43.6	172	66-71
CL163	L	0.0	20.2	43.1	166	68-73
CL172	L	0.0	18.5	44.3	151	67-72
CL271	M	0.0	17.3	44.6	163	67-72
CL272	M	0.0	16.2	45.5	174	67-72
CLXL729	L	15.0	15.8	39.5	231	69-73
CLXL745	L	50.0	16.2	39.9	212	68-73
Diamond	L	0.0	20.4	44.7	206	68-72
Jupiter	M	0.0	19.4	47.5	152	66-71
LaKast	L	0.0	15.8	44.3	208	69-73
Mermentau	L	0.0	18.0	42.9	178	67-72
Roy J	L	0.0	22.0	43.6	171	68-72
Taggart	L	0.0	18.9	45.9	181	67-71
Titan	M	0.0	17.9	47.1	157	67-70
XL753	L	0.0	15.4	41.8	245	67-72
XL760	L	0.0	18.8	41.0	239	66-71
MSX4077	L	0.0	18.1	46.0	170	66-70
Mean	--	3.4	17.7	43.7	185	67-72
$LSD_{0.05}$[c]	--	12.8	1.3	0.9	11.8	NS-1.5

[a] Grain length: L = long-grain; M = medium-grain.
[b] %HR - %TR = percent head rice - percent total white rice.
[c] LSD = least significant difference.

Table 3. Results of Craighead Co. Producer Rice Evaluation Program Trial during 2015.

Cultivar	Grain length[a]	Lodging	Moisture	Test weight	Grain yield	Milling yield[b]
		---------- (%) ----------		(lb/bu)	(bu/acre)	(%HR-%TR)
CL111	L	0.0	14.1	43.9	141	66-72
CL151	L	2.5	14.4	43.0	169	66-71
CL153	L	0.0	14.6	43.5	166	67-72
CL163	L	5.0	15.2	39.3	103	67-72
CL172	L	0.0	15.3	43.2	150	65-71
CL271	M	0.0	15.3	44.3	165	67-70
CL272	M	0.0	14.8	45.0	164	67-72
CLXL729	L	2.5	14.5	40.8	206	65-71
CLXL745	L	0.0	14.2	40.6	190	67-72
Diamond	L	0.0	15.9	45.5	187	64-71
Jupiter	M	0.0	18.0	47.7	141	61-68
LaKast	L	0.0	14.9	44.3	182	68-72
Mermentau	L	0.0	15.4	43.1	155	67-71
Roy J	L	0.0	17.2	44.8	177	66-71
Taggart	L	0.0	17.2	45.9	175	61-68
Titan	M	0.0	15.2	46.2	149	66-70
XL753	L	0.0	13.4	41.2	198	68-72
XL760	L	2.5	16.8	40.0	197	68-73
MSX4077	L	0.0	15.6	44.2	95	67-73
Mean	--	0.7	15.3	43.5	164	66-71
$LSD_{0.05}$[c]	--	NS	1.0	1.4	12.9	1.0-0.7

[a] Grain length: L = long-grain; M = medium-grain.
[b] %HR - %TR = percent head rice - percent total white rice.
[c] LSD = least significant difference.

Table 4. Results of Greene Co. Producer Rice Evaluation Program Trial during 2015.

Cultivar	Grain length[a]	Lodging	Moisture	Test weight	Grain yield	Milling yield[b]
		---------- (%) ----------		(lb/bu)	(bu/acre)	(%HR-%TR)
CL111	L	0.0	14.0	42.1	178	67-71
CL151	L	16.3	14.1	42.6	192	67-72
CL153	L	0.0	15.1	41.7	173	67-71
CL163	L	0.0	13.5	40.4	137	64-69
CL172	L	0.0	18.4	43.0	133	64-70
CL271	M	0.0	14.9	42.7	157	70-72
CL272	M	0.0	15.7	43.0	170	68-71
CLXL729	L	0.0	13.3	39.1	243	66-71
CLXL745	L	13.3	12.7	39.5	229	68-73
Diamond	L	0.0	16.6	44.3	195	66-71
Jupiter	M	0.0	18.6	46.0	142	68-71
LaKast	L	0.0	14.8	43.7	193	66-72
Mermentau	L	0.0	15.7	42.7	163	67-71
Roy J	L	0.0	20.1	42.6	151	62-70
Taggart	L	0.0	17.7	44.5	160	66-72
Titan	M	0.0	16.2	45.8	197	69-71
XL753	L	25.0	13.1	40.9	244	69-74
XL760	L	0.0	16.6	39.0	202	65-71
MSX4077	L	0.0	13.2	45.0	164	66-71
Mean	--	2.9	15.5	42.5	180	67-71
$LSD_{0.05}$[c]	--	NS	1.7	1.5	14.8	1.5-1.0

[a] Grain length: L = long-grain; M = medium-grain.
[b] %HR - %TR = percent head rice - percent total white rice.
[c] LSD = least significant difference.

Table 5. Results of Lincoln Co. Producer Rice Evaluation Program Trial during 2015.

Cultivar	Grain length[a]	Lodging	Moisture	Test weight	Grain yield	Milling yield[b]
		---------- (%) ----------		(lb/bu)	(bu/acre)	(%HR-%TR)
CL111	L	0.0	16.6	43.6	223	63-68
CL151	L	0.0	17.0	43.9	225	63-68
CL153	L	0.0	17.7	43.9	234	64-67
CL163	L	0.0	17.8	43.4	216	60-64
CL172	L	0.0	17.9	44.0	197	63-67
CL271	M	0.0	18.3	44.8	189	62-67
CL272	M	0.0	18.4	45.9	210	60-66
CLXL729	L	0.0	16.4	39.8	287	60-66
CLXL745	L	0.0	16.6	40.1	268	63-69
Diamond	L	0.0	18.8	44.1	205	55-65
Jupiter	M	0.0	21.7	49.1	196	61-64
LaKast	L	0.0	15.8	43.5	230	53-65
Mermentau	L	0.0	19.3	43.1	196	61-65
Roy J	L	0.0	19.8	44.0	192	60-68
Taggart	L	0.0	18.3	45.0	202	60-67
Titan	M	0.0	19.4	48.1	222	62-66
XL753	L	0.0	16.9	41.1	257	59-67
XL760	L	0.0	18.7	39.9	252	58-66
MSX4077	L	0.0	18.9	46.9	180	64-67
Mean	--	0.0	18.1	43.9	220	61-66
$LSD_{0.05}$[c]	--	NA	1.1	0.8	10.9	1.5-0.8

[a] Grain length: L = long-grain; M = medium-grain.
[b] %HR - %TR = percent head rice - percent total white rice.
[c] LSD = least significant difference.

Table 6. Results of Lonoke Co. Producer Rice Evaluation Program Trial during 2015.

Cultivar	Grain length[a]	Lodging	Moisture	Test weight	Grain yield	Milling yield[b]
		---------- (%) ----------		(lb/bu)	(bu/acre)	(%HR-%TR)
CL111	L	0.0	14.6	44.6	194	61-69
CL151	L	0.0	15.5	44.1	185	64-68
CL153	L	0.0	14.5	43.5	195	65-69
CL163	L	0.0	15.4	43.0	190	63-67
CL172	L	0.0	15.5	44.2	170	64-69
CL271	M	0.0	16.3	44.1	175	51-68
CL272	M	0.0	16.4	45.5	193	43-67
CLXL729	L	0.0	13.7	40.6	248	52-65
CLXL745	L	0.0	13.4	40.8	243	55-68
Diamond	L	0.0	14.3	44.2	219	60-68
Jupiter	M	0.0	18.8	47.7	181	62-67
LaKast	L	0.0	13.7	43.3	218	56-66
Mermentau	L	0.0	15.6	43.6	183	63-68
Roy J	L	0.0	16.4	43.7	205	65-70
Taggart	L	0.0	15.5	45.4	186	61-68
Titan	M	0.0	16.1	46.9	199	34-65
XL753	L	0.0	13.2	41.7	250	46-67
XL760	L	0.0	14.7	40.4	261	61-66
MSX4077	L	0.0	14.0	45.4	188	57-67
Mean	--	0.0	15.1	43.8	204	57-67
$LSD_{0.05}$[c]	--	NA	1.2	1.2	12.4	3.9-1.6

[a] Grain length: L = long-grain; M = medium-grain.
[b] %HR - %TR = percent head rice - percent total white rice.
[c] LSD = least significant difference.

Table 7. Results of Prairie Co. Producer Rice Evaluation Program Trial during 2015.

Cultivar	Grain length[a]	Lodging	Moisture	Test weight	Grain yield	Milling yield[b]
		---------- (%) ----------		(lb/bu)	(bu/acre)	(%HR-%TR)
CL111	L	0.0	13.5	42.1	145	46-67
CL151	L	0.0	14.3	43.3	153	42-68
CL153	L	0.0	13.7	40.0	190	46-67
CL163	L	0.0	13.2	40.7	196	55-67
CL172	L	0.0	13.3	40.1	184	53-68
CL271	M	0.0	13.8	42.0	176	38-67
CL272	M	0.0	13.9	44.3	177	34-67
CLXL729	L	0.0	12.8	38.1	192	44-66
CLXL745	L	0.0	13.1	39.1	152	45-68
Diamond	L	0.0	13.7	41.7	204	44-67
Jupiter	M	0.0	15.9	46.0	175	57-68
LaKast	L	0.0	13.8	43.4	193	39-66
Mermentau	L	0.0	14.3	39.9	170	57-68
Roy J	L	0.0	13.9	41.0	209	46-68
Taggart	L	0.0	13.9	41.8	193	40-67
Titan	M	0.0	13.9	45.6	191	22-65
XL753	L	0.0	13.3	40.3	227	39-67
XL760	L	0.0	12.9	39.5	202	45-66
MSX4077	L	0.0	13.6	41.6	176	50-68
Mean	--	0.0	13.7	41.6	184	44-67
$LSD_{0.05}$[c]	--	NA	0.9	2.5	22.3	3.7-1.0

[a] Grain length: L = long-grain; M = medium-grain.
[b] %HR - %TR = percent head rice - percent total white rice.
[c] LSD = least significant difference.

Table 8. Results of Woodruff Co. Producer Rice Evaluation Program Trial during 2015.

Cultivar	Grain length[a]	Lodging	Moisture	Test weight	Grain yield	Milling yield[b]
		---------- (%) ----------		(lb/bu)	(bu/acre)	(%HR-%TR)
CL111	L	0.0	12.8	45.3	172	52-69
CL151	L	0.0	13.2	43.9	147	53-69
CL153	L	0.0	13.0	44.3	143	53-70
CL163	L	1.3	13.0	42.0	161	56-69
CL172	L	1.3	12.8	44.0	151	50-68
CL271	M	3.8	12.7	43.1	162	43-67
CL272	M	1.3	12.8	44.3	161	42-68
CLXL729	L	3.8	13.2	43.4	161	50-68
CLXL745	L	3.8	12.8	41.8	174	53-69
Diamond	L	15.0	13.2	42.6	165	49-67
Jupiter	M	0.0	13.7	44.6	139	54-68
LaKast	L	1.3	12.5	44.3	169	48-69
Mermentau	L	0.0	13.9	44.5	141	52-68
Roy J	L	6.3	12.9	42.8	152	49-67
Taggart	L	0.0	13.3	44.6	138	44-67
Titan	M	5.0	14.7	45.4	167	48-68
XL753	L	1.3	13.1	42.9	193	52-69
XL760	L	12.5	13.1	42.7	154	54-68
MSX4077	L	3.8	13.0	43.6	154	51-68
Mean	--	3.2	13.1	43.7	158	50-68
$LSD_{0.05}$[c]	--	NS	NS	NS	NS	NS-NS

[a] Grain length: L = long-grain; M = medium-grain.
[b] %HR - %TR = percent head rice - percent total white rice.
[c] LSD = least significant difference.

Table 9. Rice cultivar reactions[a] to diseases (2015).

Cultivar	Sheath blight	Blast	Straight-head	Bacterial panicle blight	Narrow brown leaf Spot	Stem rot	Kernel smut	False smut	Lodging	Black sheath rot	Sheath spot
Caffey	MS	MR	--	S	R	--	--	MS	--	--	--
Cheniere	S	VS	VS	VS	S	S	S	S	MR	MS	--
CL111	VS	MS	S	VS	VS	VS	S	S	MS	S	--
CL151	S	VS	VS	VS	S	VS	S	S	MS	S	--
CL152	S	VS	S	S	MR	--	VS	S	--	--	--
CL163	S	S	--	MS	--	--	MS	--	--	--	--
CL172	MS	MS	--	MS	--	--	MS	S	--	--	--
CL271	S	MR	--	MS	MR	--	MS	--	--	S	--
CL272	S	S	--	VS	--	--	MS	--	--	--	--
CLXL729	MS	R	MS	MR	MS	S	MS	S	S	S	--
CLXL745	S	R	R	MR	MS	S	MS	S	S	S	--
Cocodrie	S	S	VS	S	S	VS	S	S	MR	S	--
Della-2	S	R	--	S	MS	--	--	--	--	--	--
Francis	MS	VS	MR	VS	S	S	VS	S	MS	S	--
Jazzman-2	VS	S	--	VS	MR	--	S	S	--	--	--
Jupiter	S	S	S	MR	MS	VS	MS	MS	S	MR	--
LaKast	S	S	MS	S	MS	S	S	S	MS	MS	S
Mermentau	S	S	VS	MS	MS	--	S	S	MS	--	--
Roy J	MS	S	S	S	MR	S	VS	S	MR	MS	--
Taggart	MS	MS	R	MS	MS	S	S	S	MS	MS	--
Titan	S	MS	--	S	--	--	S	MS	--	--	--
Wells	S	S	S	S	S	VS	S	S	MS	MS	--
XL723	MS	R	S	MR	MS	S	MS	S	MS	S	--
XL753	MS	R	MS	MR	--	--	MS	S	MS	S	--
XL760	MS	--	--	--	--	--	MS	VS	--	--	--

[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 in grower fields across Arkansas. In general, these ratings represent expected cultivar reactions to disease under conditions that most favor severe disease development. *Table prepared by Y. Wamishe, Assistant Professor/Extension Plant Pathologist*

Grain Yield Response of Six New Rice Cultivars to Nitrogen Fertilization

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ABSTRACT

The cultivar × nitrogen (N) fertilizer rate studies determine the proper N fertilizer rates for the new rice (*Oryza sativa* L.) cultivars across the array of soil and climatic conditions which exist in the Arkansas rice-growing region. The six rice cultivars studied in 2015 were: Diamond, LaKast, Titan, and Horizon Ag's Clearfield CL163, CL172, and CL271. Grain yields in 2015 at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC), Stuttgart, Ark., were typical of most years. In contrast, grain yields were lower at the Pine Tree Research Station (PTRS) near Colt, Ark., due to late planting and a zinc deficiency that appeared to harm some cultivars more than others, and at the Northeast Research and Extension Center (NEREC), Keiser, Ark., where bird damage decreased yields and increased variability of the data for most of the cultivars. This was the first year Diamond and Titan were in the cultivar × N rate study and thus there is not enough data to make a recommendation at this time. The four years of results collected for LaKast and two years of results for CL163, CL172, and CL271 indicate the cultivars should do well with minimal lodging if 150 lb N/acre is applied in a two-way split of 105 lb N/acre at preflood and 45 lb N/acre at midseason when grown on silt loam soils and 180 lb N/acre in a two-way split of 135 lb N/acre at preflood and 45 lb N/acre at midseason when grown on clay soils.

INTRODUCTION

The cultivar × N fertilizer rate studies measure the grain yield performance of the new rice cultivars over a range of N fertilizer rates on representative clay and silt loam soils and determines the proper N fertilizer rates to maximize yield on these soils

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under the climatic conditions that exist in Arkansas. Promising new rice selections from breeding programs in Arkansas, Louisiana, Mississippi, and Texas as well as those from private industry are evaluated in this study. Six new rice cultivars were entered and studied in 2015 at three locations as follows: Arkansas entered the short stature, long-grains Diamond and LaKast, and the semidwarf, medium-grain Titan; and Horizon AG entered the Clearfield short stature, long-grain cultivar CL163 (which has higher amylose content for processing quality) in cooperation with Mississippi; the short stature, long-grain CL172 in cooperation with Arkansas; and the semidwarf, medium-grain CL271 in cooperation with Louisiana. Clearfield rice cultivars are tolerant to the broad spectrum herbicide imazethapyr (Newpath).

PROCEDURES

University of Arkansas System Division of Agriculture locations where the cultivar × N fertilizer rate studies were conducted and corresponding soil series are as follows: Northeast Research and Extension Center (NEREC), Keiser, Ark., on a Sharkey clay (Vertic Haplaquepts); Pine Tree Research Station (PTRS), near Colt, Ark., on a Calloway silt loam (Glossaquic Fragiudalfs); and the Rice Research and Extension Center (RREC), near Stuttgart, Ark., on a DeWitt silt loam (Typic Albaqualfs). The experimental design utilized at all locations for each of the rice cultivars studied was a randomized complete block with four replications. A single preflood N fertilizer application was utilized for all cultivars and was applied as urea on to a dry soil surface at the 4- to 5-lf stage. The preflood N rates were: 0, 60, 90, 120, 150, 180, and 210 lb N/acre. The studies on the two silt loam soils at the PTRS and the RREC received the 0 to 180 lb N/acre fertilizer rates and the studies on the clay soil at the NEREC received the 0 to 210 lb N/acre N rates with the 60 lb N/acre rate omitted. Rice usually requires about 20 to 30 lb N/acre more N fertilizer to maximize grain yield when grown on clay soils compared to the silt loams. All of the rice cultivars were drill-seeded on the silt loams and clay soil at rates of 73 and 91 lb/acre, respectively, in plots 9 rows wide (row spacing of 7 in.), 15 ft. in length. Pertinent agronomic dates and practices at each location are shown in Table 1. The studies were flooded at each location when the rice was at the 4- to 5-lf stage and within 2 days of preflood N fertilization. The studies remained flooded until the rice was mature. At maturity, the center 5 rows of each plot were harvested, the moisture content and weight of the grain were determined, and yields were calculated as bu/acre at 12% moisture. A bushel (bu) of rice weighs 45 pounds (lb). Statistical analyses were conducted with SAS (SAS Institute Inc., Cary, N.C.) and mean separations were based upon Fisher's protected least significant difference test ($P = 0.05$) where appropriate.

RESULTS AND DISCUSSION

A single, optimum preflood N application method was adopted in 2008 in all cultivar × N fertilizer rate studies due to the rising cost of N fertilizer and the preference of the short stature and semidwarf rice plant types currently being grown. The

currently grown rice cultivars typically reach a maximum yield with less N when the N is applied in a single preflood application compared to a two-way split application. Usually the rice cultivars require 20 to 30 lb N/acre less when the N is applied in a single preflood application compared to a two-split application where the second split is applied between beginning internode elongation and 0.5-in. internode elongation. Thus, if 150 lb N/acre is recommended for a two-way split application, then 120 to 130 lb N/acre is recommended for a single preflood N application. Conditions critical for use of the single, optimum preflood N application method are: the field can be flooded timely, the urea is treated with the urease inhibitor NBPT or ammonium sulfate used, unless the field can be flooded in 2 days or less for silt loam soils and 7 days or less for clay soils, and a 2- to 4-in. flood depth is maintained for at least 3 weeks following flood establishment.

In most years, the silt loam soil at the RREC has the largest amount of plant-available/readily available native N, followed by the silt loam soil at the PTRS and then the clay soil at the NEREC. Thus, most rice cultivars typically require a lower N fertilizer rate to maximize grain yield at the RREC compared to at the PTRS or NEREC, and usually a little less at the PTRS than at the NEREC. Pertinent agronomic information such as planting, herbicide, fertilization, and flood dates are shown in Table 1. Grain yields in the 2015 cultivar × N rate studies at the RREC were typical of most years. However at the PTRS, yields were lower due to late planting and a zinc deficiency that appeared to harm some cultivars more than others; and yields were also lower at the NEREC where there was bird damage; thus the variability of the data was increased for most of the cultivars.

Diamond achieved a grain yield of 191 bu/acre on the clay soil at NEREC when 120 lb N/acre were applied preflood and maintained this grain yield when up to the maximum N rate of 210 lb N/acre was applied with no lodging (Table 2). Diamond did experience some bird damage at NEREC that probably decreased grain yields and definitely caused variability in the grain yield data, but Diamond still was able to achieve a maximum numerical yield of 197 bu/acre. The grain yield of Diamond did not significantly increase on the silt loam soils at PTRS and RREC when more than 120 lb N/acre was applied preflood and was able to maintain this yield with no lodging when up to 180 lb/acre was applied. The maximum numerical grain yield of 187 bu/acre by Diamond at the PTRS is remarkable considering the late planting and the zinc deficiency that limited the yields of some of the other cultivars in the study. Thus, over the three locations Diamond achieved a maximum grain yield of around 190 bu/acre with no lodging and appeared to have a stable yield over a wide range of N rates. This was the first year Diamond was in the N-rate study and one to two more years of research will be required before an N-rate recommendation can be made.

LaKast achieved a grain yield of 203 bu/acre when 210 lb N/acre was applied preflood, but did not significantly increase in grain yield on the clay soil at NEREC when more than 150 lb N/acre was applied preflood (Table 3). Like Diamond, LaKast did experience some bird damage at NEREC that probably decreased grain yields and definitely caused variability in the grain yield data. Somewhat similarly, previous studies (Norman et al., 2013; 2014) of the effect of N rate on the grain yield of LaKast on the

clay soil at NEREC reported maximum yields of over 200 bu/acre when 120 to 180 lb N/acre were applied preflood. The grain yield of LaKast did not significantly increase on the silt loam soil at PTRS when more than 150 lb N/acre was applied preflood and LaKast did not seem that harmed by the zinc deficiency that plagued some of the other cultivars achieving a maximum numerical yield of 186 bu/acre. Maximum grain yields of LaKast over the previous 3 years were achieved at the PTRS when 120 to 180 lb N/acre were applied preflood (Norman et al., 2013; 2014; 2015). LaKast achieved a grain yield of 189 bu/acre on the silt loam soil at the RREC when 120 lb N/acre was applied preflood and did not significantly increase in yield when up to 180 lb N/acre (195 bu/acre) was applied preflood. In the previous 3 years, LaKast had a maximum grain yield of over 200 bu/acre at RREC when 120 lb N/acre was applied preflood; although in all of those years, the grain yield never significantly increased when more than 90 lb N/acre was applied at the RREC. LaKast experienced no lodging at any of the three locations in 2015. After four years of study, it appears LaKast has a stable yield over a wide range of N rates and should do well with minimal lodging if 150 lb N/acre is applied in a two-way split of 105 lb N/acre at preflood and 45 lb N/acre at midseason when grown on silt loam soils and 180 lb N/acre in a two-way split of 135 lb N/acre at preflood and 45 lb N/acre at midseason when grown on clay soils.

Titan achieved a grain yield of 177 bu/acre when 180 lb N/acre was applied preflood on the clay soil at the NEREC and did not significantly increase in yield when the N rate was increased to 210 lb N/acre (Table 4). Bird damage was minimal on Titan at the NEREC and probably had only a minor effect on grain yield and yield variability. Similarly, the grain yield of Titan maximized when 180 lb N/acre was applied to the silt loam soil at the PTRS. Titan displayed zinc deficiency at PTRS and was slow to recover when zinc was applied. The zinc deficiency definitely had a negative impact on the grain yield of Titan at the PTRS and the late planting probably aggravated the problem. Titan achieved a grain yield of 200 bu/acre on the silt loam soil at the RREC when 150 lb N/acre was applied preflood and did not significantly increase or decrease in yield when up to 180 lb Nacre was applied. Lodging was not an issue for Titan at any of the three locations in 2015. This was the first year Titan was in the cultivar × N rate study and one to two more years of research will be required before an N-rate recommendation can be made.

The Clearfield cultivar CL163 did not significantly increase in grain yield when more than 120 lb N/acre was applied preflood on the clay soil at the NEREC and the grain and resulting yield did not appear to have been damaged by the birds (Table 5). The zinc deficiency definitely and late planting probably negatively impacted the grain yield of CL163 on the silt loam soil at the PTRS and caused the data to be more variable and the yield to not significantly increase when greater than 90 lb N/acre was applied preflood. In 2014, when the planting was timely and there was no zinc deficiency, CL163 had a maximum grain yield of 197 bu/acre at the PTRS when 120 lb N/acre was applied preflood (Norman et al., 2015). Clearfield CL163 achieved a maximum grain yield on the silt loam soil at the RREC when 150 lb N/acre was applied preflood which is higher than the 120 lb N/acre required in 2014 (Norman et al., 2015). After two years of study, it appears CL163 should do well with minimal lodging if 150 lb

N/acre is applied in a two-way split of 105 lb N/acre at preflood and 45 lb N/acre at midseason when grown on silt loam soils; and when grown on clay soils, the preflood N rate should be increased by 30 lb N/acre.

The grain yield of CL172 did not significantly increase when more than 120 lb N/acre was applied preflood on the clay soil at the NEREC and there was some bird damage that negatively affected yield and increased yield data variability (Table 6). The cultivar CL172 maintained a grain yield of about 165 bu/acre when the N rate increased to as high as 210 lb N/acre with no lodging at the NEREC. The zinc deficiency at the PTRS was particularly harmful to CL172 and caused it to reach a maximum yield of only 146 bu/acre on the silt loam soil. Grain yields did not significantly increase at the PTRS when more than 120 lb N/acre was applied. When grown on the silt loam soil at the PTRS in 2014, CL172 obtained a grain yield of 192 bu/acre when 150 lb N/acre was applied preflood (Norman et al., 2015). The yield of CL172 did not significantly increase at the RREC when more than 150 lb N/acre was applied preflood in 2015 and had a maximum numerical yield of 169 bu/acre. In 2014, CL172 obtained a maximum yield of 194 bu/acre when 120 lb N/acre was applied preflood on the silt loam soil at RREC (Norman et al., 2015). After two years of study, CL172 appears to have a stable yield over a wide range of N rates once the N rate to achieve maximum yield is approached and exceeded. Cultivar CL172 should do well with minimal lodging if 150 lb N/acre is applied in a two-way split of 105 lb N/acre at preflood and 45 lb N/acre at midseason when grown on silt loam soils and a two-way split of 135 lb N/acre at preflood and 45 lb N/acre at midseason when grown on clay soils.

The medium grain CL271 achieved a grain yield of 183 bu/acre when 180 lb N/acre was applied preflood on the clay soil at the NEREC and maintained this grain yield when the N rate increased to 210 lb N/acre (Table 7). The cultivar CL271 experienced minimal bird damage at the NEREC. The grain yield of CL271 did not significantly increase above 164 bu/acre on the silt loam soil at the PTRS when more than 120 lb N/acre was applied preflood. The zinc deficiency coupled with the late planting negatively affected the yield and the yield variability of CL271 at the PTRS in 2015. For instance in 2014 at the PTRS, CL271 obtained a grain yield of 203 bu/acre when 120 lb N/acre was applied preflood and did not significantly increase or decrease in yield (209 bu/acre) when up to 180 lb N/acre was applied preflood (Norman et al., 2015). On the silt loam soil at the RREC, CL271 did not significantly increase in yield when more than 150 lb N/acre was applied preflood and reached a maximum yield of only 162 bu/acre. This is somewhat in contrast to the results in 2014 when CL271 obtained a maximum yield of 196 bu/acre at the RREC when 150 lb N/acre was applied preflood; although it did not significantly increase in yield above the 189 bu/acre obtained when 90 lb N/acre was applied preflood (Norman et al., 2015). After two years of study, CL271 appears to have a stable yield over a wide range of N rates once the N rate to achieve maximum yield is approached and exceeded. This cultivar should do well with minimal lodging if 150 lb N/acre is applied in a two-way split of 105 lb N/acre at preflood and 45 lb N/acre at midseason when grown on silt loam soils and a two-way split of 135 lb N/acre at preflood and 45 lb N/acre at midseason when grown on clay soils.

The Wells rice cultivar was included in the study as a control and to give a frame of reference for comparing the grain yield performance and lodging percentage of the

new cultivars over the N fertilizer rates applied at the three locations (Table 8). The N-rate recommendation for Wells is 150 lb N/acre applied in a two-way split of 105 lb N/acre at preflood and 45 lb N/acre at midseason when grown on silt loam soils and a two-way split of 135 lb N/acre at preflood and 45 lb N/acre at midseason when grown on clay soils.

SIGNIFICANCE OF FINDINGS

The cultivar × N fertilizer rate study examines the grain yield performance of a new rice cultivar across a range of N fertilizer rates on representative soils and under climatic conditions that exist in the Arkansas rice-growing region. Thus, this study enables the estimation of the proper N fertilizer rate for a cultivar to achieve maximum grain yield when grown commercially in the Arkansas rice-growing region. The six cultivars studied in 2015 were: Diamond, LaKast, Titan, CL163, CL172, and CL271. The data generated from multiple years of testing of each cultivar will be used to determine the proper N fertilizer rate to achieve maximum yield when grown commercially on most silt loam and clay soils in Arkansas.

ACKNOWLEDGMENTS

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Table 1. Pertinent agronomic information for the Northeast Research and Extension Center (NEREC), Keiser, Ark.; the Pine Tree Research Station (PTRS), near Colt, Ark.; and the Rice Research and Extension Center (RREC), Stuttgart, Ark., during 2015.

Practices	NEREC	PTRS	RREC
Preplant fertilizers	----	----	90 lb P_2O_5/acre, 90 lb K_2O/acre + 10 lb Zn/acre
Planting date	4 May	5 June	1 May
Emergence date	20 May	11 June	10 May
Herbicide spray date and procedures	6 May 1.3 pt Command/acre + 40 oz Facet L/acre + 0.75 oz/acre Permit Plus	5 May 1.0 pt/acre Command + 0.75 oz/acre Permit Plus	1 May 20 oz Obey/acre
Herbicide spray date and procedures	11 June 4 qt /acre Stam + 1.0 pt/acre Grandstand	16 June 3 qt/acre Riceshot + 32 oz/acre Facet L	1 June 2 qt/acre Prowl + 0.75 oz/acre Permit Plus
Herbicide spray date and procedures	-----	23 June 32 oz/acre Facet L + 1.0 pt/acre Bolero	----
Preflood N date	18 June	24 June	3 June
Flood date	19 June	25 June	4 June
Drain date	9 September	1 October	28 August
Harvest date	23 September	14 October	2 September

Table 2. Influence of nitrogen (N) fertilizer rate on the grain yield of Diamond rice at three locations during 2015.

	Grain yield		
N fertilizer rate	**NEREC[a]**	**PTRS**	**RREC**
(lb N/acre)	----------	**(bu/acre)**	----------
0	62	70	85
60	----	127	148
90	148	153	169
120	191	177	183
150	191	187	192
180	197	180	194
210	189	----	----
$LSD_{0.05}$[b]	24.4	12.0	11.6

[a] NEREC = Northeast Research and Extension Center, Keiser, Ark.; PTRS = Pine Tree Research Station, near Colt, Ark.; and RREC = Rice Research and Extension Center, Stuttgart, Ark.

[b] LSD = least significant difference.

Table 3. Influence of nitrogen (N) fertilizer rate on the grain yield of LaKast rice at three locations during 2015.

	Grain yield		
N fertilizer rate	**NEREC[a]**	**PTRS**	**RREC**
(lb N/acre)	----------	**(bu/acre)**	----------
0	76	81	89
60	----	133	144
90	162	149	173
120	178	168	189
150	192	176	188
180	194	186	195
210	203	----	----
$LSD_{0.05}$[b]	21.1	10.6	15.3

[a] NEREC = Northeast Research and Extension Center, Keiser, Ark.; PTRS = Pine Tree Research Station, near Colt, Ark.; and RREC = Rice Research and Extension Center, Stuttgart, Ark.

[b] LSD = least significant difference.

Table 4. Influence of nitrogen (N) fertilizer rate on the grain yield of Titan rice at three locations during 2015.

	Grain yield		
N fertilizer rate	**NEREC[a]**	**PTRS**	**RREC**
(lb N/acre)	----------	**(bu/acre)**	----------
0	74	56	93
60	----	92	150
90	145	108	163
120	158	127	180
150	164	137	200
180	177	150	191
210	179	----	----
$LSD_{0.05}$[b]	10.0	10.4	10.5

[a] NEREC = Northeast Research and Extension Center, Keiser, Ark.; PTRS = Pine Tree Research Station, near Colt, Ark.; and RREC = Rice Research and Extension Center, Stuttgart, Ark.

[b] LSD = least significant difference.

Table 5. Influence of nitrogen (N) fertilizer rate on the grain yield of Clearfield CL163 rice at three locations during 2015.

	Grain yield		
N fertilizer rate	**NEREC[a]**	**PTRS**	**RREC**
(lb N/acre)	----------	**(bu/acre)**	----------
0	67	77	81
60	----	127	135
90	152	152	152
120	153	158	155
150	161	143	171
180	165	150	161
210	161	----	----
$LSD_{0.05}$[b]	12.7	14.6	7.3

[a] NEREC = Northeast Research and Extension Center, Keiser, Ark.; PTRS = Pine Tree Research Station, near Colt, Ark.; and RREC = Rice Research and Extension Center, Stuttgart, Ark.

[b] LSD = least significant difference.

Table 6. Influence of nitrogen (N) fertilizer rate on the grain yield of Clearfield CL172 rice at three locations during 2015.

	Grain yield		
N fertilizer rate	**NEREC[a]**	**PTRS**	**RREC**
(lb N/acre)	----------	**(bu/acre)**	----------
0	64	60	67
60	----	104	123
90	135	126	146
120	154	141	154
150	164	146	166
180	165	146	169
210	167	----	----
$LSD_{0.05}$[b]	16.2	7.3	14.5

[a] NEREC = Northeast Research and Extension Center, Keiser, Ark.; PTRS = Pine Tree Research Station, near Colt, Ark.; and RREC = Rice Research and Extension Center, Stuttgart, Ark.

[b] LSD = least significant difference.

Table 7. Influence of nitrogen (N) fertilizer rate on the grain yield of Clearfield CL271 rice at three locations during 2015.

	Grain yield		
N fertilizer rate	**NEREC[a]**	**PTRS**	**RREC**
(lb N/acre)	----------	**(bu/acre)**	----------
0	77	66	67
60	----	125	110
90	155	144	123
120	167	164	149
150	174	170	158
180	183	175	162
210	183	----	----
$LSD_{0.05}$[b]	8.3	14.8	9.8

[a] NEREC = Northeast Research and Extension Center, Keiser, Ark.; PTRS = Pine Tree Research Station, near Colt, Ark.; and RREC = Rice Research and Extension Center, Stuttgart, Ark.

[b] LSD = least significant difference.

Table 8. Influence of nitrogen (N) fertilizer rate on the grain grain yield of Wells rice at three locations during 2015.

	Grain yield		
N fertilizer rate	**NEREC[a]**	**PTRS**	**RREC**
(lb N/acre)	----------	**(bu/acre)**	----------
0	63	55	57
60	----	102	106
90	134	126	127
120	162	148	149
150	181	162	165
180	191	173	162
210	192	----	----
$LSD_{0.05}$[b]	11.0	7.9	9.5

[a] NEREC = Northeast Research and Extension Center, Keiser, Ark.; PTRS = Pine Tree Research Station, near Colt, Ark.; and RREC = Rice Research and Extension Center, Stuttgart, Ark.

[b] LSD = least significant difference.

Response of Two Rice Cultivars to Midseason Nitrogen Fertilizer Application Timing in the Presence of a Zinc Deficiency

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ABSTRACT

A midseason nitrogen (N) application timing rice (*Oryza sativa* L.) study was being conducted at the University of Arkansas System Division of Agriculture's Pine Tree Research Station (PTRS) in 2015 when a zinc (Zn) deficiency was noticed on 8 July; around beginning internode elongation (BIE) for Mermentau and about a week before BIE for Roy J. The grain yield results clearly reflected the more severe damage the Zn deficiency inflicted on the semidwarf Mermentau compared to the standard stature Roy J that appeared to have yields typical or greater for a June seeding date. One reason may be the stage of growth when the Zn deficiency was first observed. Mermentau was already at BIE and the end of vegetative growth whereas Roy J was about a week away from BIE. Another reason may be Mermentau is a semidwarf and therefore more susceptible to Zn deficiency compared to a short stature cultivar like Roy J. Visual observation indicated that Mermentau had greater stunting, greater loss of stand, and less tillering than Roy J. The yield results suggested that when a Zn deficiency occurs in a semidwarf like Mermentau a two-way split may result in a greater grain yield compared to a single preflood application and it might be better to delay the midseason application until BIE + 14 to 21 days.

INTRODUCTION

Zinc deficiency typically occurs in rice during early vegetative growth and shortly after application of the permanent flood. It is most often observed when rice is grown on silt and sandy loam soils with a pH above 7. Causes of Zn deficiency in rice in Arkansas are typically from the use of irrigation water high in $CaHCO_3$, excessive

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application of lime and/or non-uniform lime distribution. Visual symptoms associated with Zn deficiency during the early vegetative growth stage of rice are: i) basal chlorosis of newest/youngest leaves; ii) midrib of lower/oldest leaves becomes yellow to white; iii) loss of leaf turgidity causing floating leaves; iv) bronzing of older leaves; v) inhibition of tillering; vi) eventual stand loss under flooded conditions; vii) stacked leaf collars; and vii) delayed maturity (Norman et al., 2003).

A midseason N application timing study was being conducted at the University of Arkansas System Division of Agriculture's Pine Tree Research Station (PTRS), near Colt, Ark., in 2015 when a Zn deficiency was noticed on 8 July: around beginning internode elongation (BIE) for Mermentau and about a week before BIE for Roy J. Typical Zn deficiency symptomology was observed such as bronzing, stunting, loss of some stand, and atypical tillering; especially for the semidwarf Mermentau and not so much for the short stature Roy J. It was decided the severity of the Zn deficiency warranted the application of Zn, but not the removal of the flood. We thought this would be a good opportunity to measure the influence of a Zn deficiency on the grain yield of a semidwarf and a short stature rice cultivar when N was applied in a two-way split with different midseason N application timings and a single preflood application.

PROCEDURES

The study was conducted in 2013 at the PTRS, near Colt, Ark., on a Calhoun silt loam that had a pH of 7.8 and a Zn concentration of 2.1 parts per million, which is considered low. The two conventional rice cultivars in the study were the Louisiana semidwarf, long-grain Mermentau and the Arkansas short stature, long-grain Roy J. Two preflood N rates of 85 and 105 lb N/acre were utilized along with four midseason N application timings. The midseason N rate of 45 lb N/acre was applied at BIE, BIE+7 days, BIE+14 days, or BIE+21 days. There was a check or no midseason N application and a single preflood N application of 130 lb N/acre. The preflood N was applied onto dry soil just prior to flooding and the midseason N was applied directly into the floodwater. The permanent flood was established the day after the preflood N was applied when the rice was at the 4- to 6-lf stage and the flood maintained until the rice was mature.

The rice was drill-seeded at a rate of 73 lb/acre in plots 9 rows wide (row spacing of 7 in.), 15 ft in length. The rice was seeded at the PTRS on 5 June, emerged 11 June, the preflood N applied 24 June, and the BIE application was applied on 15 July for Mermentau and 21 July for Roy J. Zinc EDTA at 1 lb Zn/acre was applied on 10 July. At maturity, the center 5 rows of each plot were harvested, the moisture content and weight of the grain were determined, and yields were calculated as bu/acre at 12% moisture. A bushel (bu) of rice weighs 45 pounds (lb).

The treatments were arranged as a randomized complete block, 2 (cultivar) × 2 (preflood N rate) × 4 (midseason N application time), factorial design with four replications, a no midseason N application (control) with four replications, and a single preflood N application with four replications was included. Analysis of variance was performed on the grain yield data utilizing SAS v. 9.1 (SAS Institute, Inc., Cary, N.C.).

Differences among means were compared using Fisher's protected least significant difference (LSD) procedure at a $P = 0.05$ probability level.

RESULTS AND DISCUSSION

Analysis of variance P values for the studies indicated there was no significant ($P = 0.05$) three-way interactions of cultivar × preflood N rate × midseason N timing ($P = 0.9467$) on rice grain yield (Table 1). However, there were significant two-way interactions on rice grain yield of cultivar × preflood N rate ($P < 0.0274$) and cultivar × midseason N timing ($P = 0.0480$), but not preflood N rate × midseason N timing ($P = 0.5354$).

Roy J had a substantially greater response to N fertilizer application than did Mermentau (Table 2). Roy J obtained substantially greater grain yields than Mermentau when 85 or 105 lb N/acre was applied preflood and 45 lb N/acre was applied at midseason as well as when 130 lb N/acre was applied in a single preflood N application. Mermentau had a greater yield when the N fertilizer was applied in a two-way split application regardless of the preflood N rate compared to a single preflood application. Somewhat similarly, Roy J had a greater yield when the N fertilizer was applied in a two-way split application of 105 lb N/acre preflood and 45 lb N/acre at midseason compared to when the N was applied in a single preflood application of 130 lb N/acre or when the N was applied in a two-way split of 85 lb N/acre preflood and 45 lb N/acre at midseason with the latter two being similar. The grain yield results clearly reflected the more severe damage the Zn deficiency inflicted on Mermentau compared to Roy J. One reason may be the stage of growth when the Zn deficiency was first observed and corrected with an application of Zn. Mermentau was already at BIE and the end of vegetative growth whereas Roy J was about a week away from BIE and still had a week of vegetative growth to recover. Another reason may be that Mermentau is a semidwarf and more susceptible to Zn deficiency compared to a short stature cultivar like Roy J. Visual observation indicated that Mermentau had greater stunting, greater loss of stand, and less tillering than Roy J.

Mermentau did not significantly increase in grain yield from the midseason N application of 45 lb N/acre until the midseason N was applied at BIE + 14 or 21 days (Table 3). The greatest yield increase Mermentau displayed from the midseason N application was only 12 bu/acre. Mermentau obtained a maximum yield of 145 bu/acre when midseason N was applied which was substantially greater than the 119 bu/acre with the single preflood application. Additionally, Mermentau produced a significantly greater yield of 133 bu/acre when no midseason N was applied (preflood N rates of 85 and 105 lb N/acre averaged) compared to when 130 lb N/acre was applied in a single preflood N application. These results, along with those in Table 2, indicate that preflood N had a significant impact on the severity of Zn deficiency in Mermentau with severity apparently increasing as the preflood N rate increased. By contrast, when the midseason N was delayed until 14 or 21 days past BIE, the yield of Mermentau significantly increased compared to when no midseason N was applied or when it was

applied at BIE or BIE + 7 days. Perhaps Mermentau responded better to the later midseason N applications compared to the earlier applications because it had more time to recover from the Zn deficiency; then again, previous studies (Norman et al., 2014) on midseason N timing has shown a tendency at times for grain yield to increase as the midseason N application time was delayed. Mermentau recovered somewhat from the Zn deficiency as the season went along; however, remnants of the Zn deficiency were observable even at maturity.

Application of midseason N to Roy J did not significantly increase grain yield compared to no midseason N until it was delayed until BIE + 7 to 21 days and the yield was greater when the midseason N was delayed until BIE + 21 days compared to at BIE (Table 3). The yield of Roy J was greater with the single preflood N application than when no midseason N was applied and similar to when midseason N was applied at all of the application times. Although it should be mentioned that when the midseason N was delayed until BIE + 21 days, the yield was close to being significantly greater than the yield with the single preflood N application. As with Mermentau, Roy J may have responded better to the later midseason N applications compare to the earlier applications because it had more time to recover from the Zn deficiency. However, as mentioned earlier, previous studies (Norman et al., 2014) on midseason N timing has shown a tendency at times for grain yield to increase as the midseason N was delayed. Roy J displayed only mild Zn deficiency symptoms and as the season went along the deficiency was less observable with no noticeable deficiency symptoms displayed by heading or ostensibly in the grain yield results, especially for a June seeding date.

SIGNIFICANCE OF FINDINGS

The grain yield results clearly reflected the more severe damage the Zn deficiency inflicted on the semidwarf Mermentau compared to the standard stature Roy J that appeared to have yields typical or greater than typical for a June seeding date. One reason may be the stage of growth when the Zn deficiency was first observed with Mermentau already at the end of vegetative growth, BIE; whereas Roy J was about a week away from BIE. Another reason may be that Mermentau is a semidwarf and more susceptible to Zn deficiency compared to a short stature cultivar like Roy J. Visual observation indicated that Mermentau had greater stunting, greater loss of stand, and less tillering than Roy J. Although Mermentau recovered from the Zn deficiency as the season went along, remnants of the Zn deficiency were observable even at maturity. By contrast, Roy J displayed only mild Zn deficiency symptoms; and as the season went along the deficiency was less observable with no noticeable deficiency symptoms displayed by heading or apparently in the grain yield results. The yield results suggested that when a Zn deficiency occurs in a semidwarf like Mermentau, a two-way split may result in a greater grain yield compared to a single preflood application and it might be better to delay the midseason application until at least BIE + 14 to 21 days.

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Table 1. Analysis of variance *P* values for rice grain yield as affected by rice cultivar, preflood N rate, and midseason N timing at the Pine Tree Research Station during 2015.

Source	*P* values
Cultivar (Cul)	<0.0001
Preflood N rate (Pfn)	0.0011
Midseason N timing (Msn)	<0.0001
Cul × Pfn	0.0274
Cul × Msn	0.0480
Pfn × Msn	0.5354
Cul × Pfn × Msn	0.9467

Table 2. Influence of preflood N rate and cultivar, averaged over midseason N timing, on rice grain yield at the Pine Tree Research Station, near Colt, Ark., during 2015.

	Grain yield	
Preflood N rate	**Mermentau**	**Roy J**
(lb N/acre)	**---------- (bu/acre) ----------**	
85†	135 c	168 b
105†	138 c	180 a
130‡	119 d	172 b
$LSD_{0.05}$ §	5.9	

† An additional 45 lb N/acre was applied at midseason to these preflood N rates.
‡ Single preflood N fertilizer application with no midseason N.
§ LSD = least significant difference.

Table 3. Influence of midseason (MS) N application timing and cultivar, averaged over preflood N rate, on rice grain yield at the Pine Tree Research Station during 2015.

	Grain yield	
MS N timing†	**Mermentau**	**Roy J**
	---------- (bu/acre) ----------	
No MS N	133 e	161 c
BIE‡	129 e	170 bc
BIE + 7days	131 e	179 ab
BIE + 14days	145 d	178 ab
BIE + 21days	145 d	181 a
SPF§	119 f	172 ab
$LSD_{0.05}$ ¶	9.3	

† 45 lb N/acre was applied at midseason to all BIE treatments.
‡ BIE = beginning internode elongation.
§ SPF = single preflood fertilizer application of 130 lbs N/A with no midseason N.
¶ LSD = least significant difference.

Rice Cultivar Yield Response to Delayed Preflood Nitrogen Application and Flood Establishment Time

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ABSTRACT

The preflood nitrogen (N) application must sometimes be delayed to obtain the dry soil conditions that allow for maximal rice uptake of the fertilizer-N. Our research objective was to determine the influence of preflood urea-N/flooding application time on the grain yield of selected rice cultivars. Three trials were conducted in 2015 with each involving five urea-N rates, two to five rice cultivars and five or six fertilizer-N application and flood establishment times that ranged from 296 to 1640 cumulative Degree-Day 50 (DD50) units following emergence. For this report, only yield results from rice fertilized with 160 lb N/acre will be presented since this treatment consistently maximized grain yield. For each site, grain yield data were regressed across the cumulative DD50 units at the time of fertilizer-N application. The rice yield results suggest that the preflood-N can be delayed longer than is currently recommended without harming rice yield, even when no other fertilizer-N was applied during the seedling stage. For most cultivars and sites, application of the preflood-N and flooding at 650 to 1000 DD50s after emergence appears to maximize yield. The yield of some cultivars was not reduced when fertilizer-N was delayed beyond this range of DD50 accumulation. Results show that rice grain yields can be maximized by a wide range of preflood-N application timings provided other aspects of rice management including timely flood establishment and weed control can be managed appropriately.

INTRODUCTION

The application of the preflood urea-N to rice must sometimes be delayed to obtain the dry soil condition that is desired to slow the transformation of urea-N to NH_3-N or NO_3-N and obtain maximal N uptake. Research on this topic is limited to work pub-

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lished by Norman et al. (1992) who reported that preflood-applied N could be delayed up to 3 weeks past the 5-lf stage without loss of rice yield potential. Interest in how long preflood-N can be delayed without yield loss has been stimulated by the need to reduce water use, the availability of shorter-season cultivars and hybrids, and several consecutive years of wet field conditions when rice is ready for preflood-N application. Knowledge of how rice responds to preflood-N timing under different native soil-N availabilities and among cultivars and hybrids is needed to aid growers in making the proper decisions on fertilization.

The current recommendations suggest the optimum time to apply preflood-N is 350 to 550 Degree-Day 50 (DD50) units after rice emergence provided the soil is dry. If the soil is wet during this recommended period, growers should delay preflood-N application until a time that is about 3 weeks before the predicted 0.5-in. internode elongation. Based on this recommendation, early-season cultivars have a shorter window for preflood-N application than longer-season cultivars. Upon reviewing the available literature, we could find no information stating how the current recommendation for preflood-N timing was developed and presume that the practice of flooding fields near the 4- to 5-lf stage became accepted primarily to reduce weed competition and control practices (Johnston and Miller, 1973).

Our research objective was to determine the influence of preflood-N/flooding application time on the grain yield of selected rice cultivars. The goal of this project is to provide growers with the information they need to manage preflood fertilizer-N when field conditions deviate from the standard recommended practice and to establish the best time to apply preflood-N and the permanent flood to rice grown in the direct-seeded, delayed-flood production system.

PROCEDURES

Trials were established on a Calhoun silt loam in two different fields (A and B) at the University of Arkansas System Division of Agriculture's Pine Tree Research Station (PTRS) and on a Dewitt silt loam at the Rice Research Extension Center (RREC). Rice was seeded on 8 April at PTRS-A, 1 May at PTRS-B, and 1 May at the RREC. Rice management differed from the standard recommended practices only in regard to the time of fertilizer-N application and establishing the permanent flood, which was the primary factor being examined in these experiments. The research area at each site was managed using standard practices for stand establishment, phosphorus and potassium fertilization and pest control to ensure these factors were not yield limiting. Weed control varied among the fertilization time treatments within each site (data not shown) since we did not want weed infestations to influence rice yield potential. Thus, we assume that the additional weed control measures required in the delayed flooding treatments had no beneficial or detrimental effect on rice yield potential beyond the control measures that were performed across all fertilization times.

The PTRS-A site contained four cultivars including CL111, LaKast, Roy J, and Jupiter. Roy J and RiceTec XL753 were seeded at PTRS-B. The RREC trial included

CL111, LaKast, XL753, Roy J, and Jupiter. Within each fertilization time, each cultivar was represented within a single bay and the order of the cultivars was the same within each bay. The bays were flooded sequentially (not in random order) to facilitate management including establishing the flood, draining floodwater at maturity, and harvest.

At each site, urea-N treated with 3 qt Agrotain Ultra®/ton urea was applied at rates of 0 to 160 lb N/acre in 40 lb N/acre increments on five or six different dates after rice had reached the 3-lf stage (Tables 1-3). At each preflood-N fertilization time, urea-N was applied to a dry soil surface and flooded 2 or 3 days after preflood-N application at the RREC and PTRS, respectively. The intended time interval between preflood-N fertilization/flood times was 7 days but times were adjusted as needed to apply urea-N to a dry soil surface. No midseason-N was applied at any site. Heading progress notes and grain yield were measured on all cultivars at each site. Harvest at each site was performed with the same small-plot combine, but at different times since rice heading and maturation was different among N fertilization times (Tables 1-3). Grain yield data from each plot were adjusted to 12% moisture for statistical analysis.

At each site, each fertilization time was a randomized complete block design (RCB) with each preflood-N rate represented within each of four blocks. For simplification, only grain yield data from the greatest preflood-N rate (160 lb N/acre) was used in the analysis of variance as an RCB because it produced among the highest yields of all N rates at each fertilization time. When appropriate, means were separated using Fisher's least significant difference test. Yield differences were interpreted as significant at the $P \leq 0.10$ level.

RESULTS AND DISCUSSION

The estimated time of 50% heading was affected by the time of preflood-N/flood application with heading being delayed as preflood-N/flood application was delayed (Fig. 1). The date of 50% heading was delayed by nearly 3 weeks when preflood-N application and flooding was delayed from 28 May to 25 June. Rice in the two trials located at the PTRS showed a similar response in delayed maturation (data not shown).

The four rice cultivars grown at PTRS-A exhibited different responses to preflood-N fertilization/flood application time (Table 1). The initial N fertilization time in this field was delayed for more than a week due to wet soil conditions once seedling rice had accumulated >250 DD50s. Grain yield of the two earliest maturing cultivars, CL111 and LaKast, was not affected by N fertilization time. The yield of Jupiter rice was lowest when the preflood-N was applied at the first two application times (578 and 872 DD50s) and greatest when the preflood-N was applied 1244 or 1401 DD50s after emergence. Preflood-N applied at the other two times produced intermediate yields for Jupiter. Roy J yields were constant for the first four N fertilization times and then decreased when urea-N was applied after 17 June (1244 DD50 units).

The grain yield of Roy J and XL753 rice seeded at the PTRS-B were both affected by preflood-N/flood application time (Table 2). Maximal yield for both genotypes was produced when the preflood-N was applied 552 to 941 cumulative DD50s after rice

emergence. The lowest yields were produced when preflood-N was applied before 300 and after 1100 DD50s had accumulated. The lower yields of the XL753 fertilized 1357 DD50s after rice emergence were partially attributed to substantial lodging (45%) that occurred before harvest. Roy J rice did not lodge. Overall, the results from these two cultivars at PTRS-B suggest that applying preflood-N/flood too early or too late can be detrimental to grain yield.

Like the cultivar-specific yield results reported for the rice at the PTRS, the effect of N fertilization/flood application time differed among the five rice cultivars seeded at the RREC (Table 3). The yields of LaKast and XL753 were not influenced by preflood-N fertilization time. The yield of CL111 was lowest for rice fertilized before 610 DD50s had accumulated and greatest when rice was fertilized when 821 DD50s had accumulated before decreasing slightly on the two final fertilization times (1001 and 1253 DD50s). For Jupiter, there was no clear pattern in the yield response to preflood-N/flood application time. Yields were greatest when fertilizer-N was applied on the first (453 DD50s) and last (1253 DD50s) times, intermediate when applied at 821 DD50s, and lowest on the second (610 DD50s) and fourth (1001 DD50s) times. Roy J grain yields were greatest when preflood-N/flood was applied at 1001 DD50s compared to all other application times, which were equal but 14 to 22 bu/acre lower than the yields produced when preflood-N/flood was applied at 1001 DD50s.

SIGNIFICANCE OF FINDINGS

The rice yield results from three trials and multiple cultivars seeded in 2015 suggest that the preflood urea-N/flood can probably be delayed longer than is currently recommended without harming rice yield, even when no other fertilizer-N is applied during the seedling stage. The current recommendation indicates preflood-N should be applied no later than 510 DD50s before the predicted date of 0.5-in. internode elongation and assumes that rice development occurs consistently regardless of N availability and flooding. For most cultivars and hybrids, it appears that the optimal time to apply preflood-N/flood may be 650 to 1000 DD50s after emergence. The yield of some cultivars was not reduced when fertilizer-N was delayed beyond this range of DD50 accumulation. While the results clearly show that preflood-N ferftilizer application can be substantially delayed, delaying the flood influences other aspects of rice management with the most obvious effects experienced in 2015 being the need for additional weed control and delayed maturity when the fertilizer-N and flood were delayed several weeks beyond the 4- to 5-lf stage. The results from 2015 suggest that cultivars may respond to delayed preflood-N/flood differently. The different responses for rice cultivars seeded at the same site could be due to differences in weather (e.g., rainfall and temperatures) at critical times (e.g., flowering) that influenced grain yield. Thus, conclusions from the 2015 trial results should be evaluated with caution. When this study is concluded, results from all preflood N rates and measurements will need to be examined to consider the advantages and disadvantages in relation to rice management, use of natural resources, and the economic implications for rice growers.

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Table 1. The date, cumulative Degree-Day 50 (DD50) units, and grain yield of four rice cultivars as affected by preflood-N fertilization/flood date for rice seeded on 8 April 2016 at the Pine Tree Research Station, near Colt, Ark.

Fertilization time		Cultivar			
Date	Cumulative DD50 units	CL111	Jupiter	LaKast	Roy J
		(bu/acre)			
23 May	578	167 a	174 d	174 a	175 ab
4 June	834	159 a	167 d	165 a	174 ab
8 June	944	161 a	196 c	160 a	178 ab
17 June	1244	154 a	218 ab	177 a	187 a
23 June	1401	152 a	222 a	178 a	172 b
1 July	1640	151 a	209 b	174 a	140 c
$LSD_{0.10}$		NS†	12	NS	14
P-value		0.4497	<0.0001	0.3178	0.0005

† NS = not significant.

Table 2. The date, cumulative Degree-Day 50 (DD50) units, and grain yield of Roy J and RiceTec XL753 as affected by preflood-N fertilization/flood date for rice seeded on 1 May 2016 at the Pine Tree Research Station, near Colt, Ark.

Fertilization time		Cultivar	
Date	Cumulative DD50 units	Roy J	XL753
		----------(bu/acre)----------	
23 May	296	154 d	211 c
4 June	552	187 ab	236 a
8 June	659	197 a	228 ab
17 June	941	183 b	214 bc
23 June	1118	168 c	207 c
1 July	1357	169 c	190 d
$LSD_{0.10}$		11	15
P-value		0.0001	0.011

Table 3. The date, cumulative Degree-Day 50 (DD50) units, and grain yield of five rice cultivars as affected by preflood-N fertilization/flood date for rice seeded on 1 May 2016 at the Rice Research Extension Center, near Stuttgart, Ark.

Fertilization time		Cultivar				
Date	Cumulative DD50 units	CL111	Jupiter	LaKast	Roy J	XL753
		----------(bu/acre)----------				
28 May	453	126 d	196 a	181 a	183 b	241 a
4 June	610	132 cd	144 c	179 a	191 b	229 a
11 June	821	152 a	179 b	179 a	191 b	231 a
17 June	1001	139 bc	148 c	171 a	205 a	240 a
25 June	1253	141 b	207 a	186 a	183 b	228 a
$LSD_{0.10}$		8	13	NS†	11	NS
P-value		0.0057	<0.0001	0.1586	0.0187	0.5368

† NS = not significant.

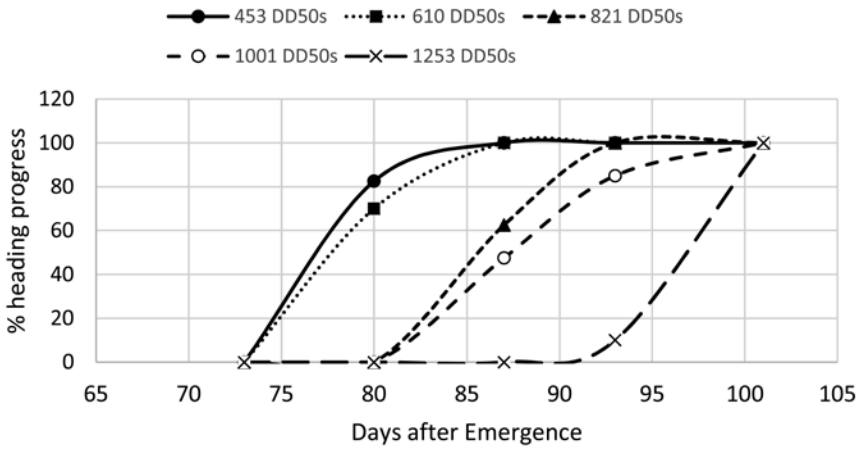

Fig. 1. Heading progress of Roy J rice receiving 160 lb urea-N/acre preflood as affected by application and flood establishment timing in an experiment conducted at the Rice Research Extension Center, near Stuttgart, Ark., in 2015.

Response of Two Rice Cultivars to Midseason Nitrogen Fertilizer Application Timing

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ABSTRACT

A study was conducted at two locations in 2015 to examine the influence of midseason nitrogen (N) application and its timing on the grain yield of conventional, pure-line rice (*Oryza sativa* L.) cultivars from Louisiana and Arkansas. The conventional rice cultivars chosen for the study at the University of Arkansas System Division of Agriculture's Northeast Research and Extension Center (NEREC) and Rice Research and Extension Center (RREC) were the Louisiana semidwarf, long-grain Mermentau and the Arkansas short stature, long-grain Roy J. There were two preflood N rates and four midseason N application timings at beginning internode elongation (BIE), BIE + 7 days, BIE + 14 days, and BIE + 21 days. There was also a control, or no midseason N application, and a single preflood N application. It should be noted that issues at the NEREC such as difficulty maintaining a flood and bird damage increased the variability of the data and probably affected the mean grain yields. Roy J produced a greater grain yield than Mermentau at the NEREC and RREC. A single preflood N application produced a similar or greater yield than the two-way split application at both the NEREC and RREC. Application of midseason N increased grain yield when applied at BIE + 21 days at the NEREC and at BIE + 7, BIE + 14, or BIE + 21 days at the RREC, while other earlier midseason N application times did not significantly increase grain yield. Grain yield increased as the midseason N was delayed at the RREC, but not at the NEREC. Results from this and previous studies have led to the new recommendation that the midseason N application should be applied no earlier than BIE and at least 3 weeks after the preflood N application; both of these conditions have to be met to obtain the full grain yield benefit from the midseason N application.

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INTRODUCTION

Nitrogen fertilizer typically is applied in a two-way split application for conventional, pure-line rice cultivars in dry-seeded, delayed-flood systems (Norman et al., 2013b).The first N application is applied preflood, onto dry soil, at beginning tillering and the second N application occurs into the floodwater at midseason between beginning internode elongation (BIE) and BIE + 7 days, or approximately 0.5-inch internode elongation (IE; Norman et al., 2013b). The preflood N application is the larger of the two and ranges, for pure-line cultivars, from 75 to 105 lb N/acre depending on the cultivar (Roberts and Hardke, 2015). The preflood N rate is increased by 30 lb N/acre for rice grown on clay soils, but the midseason N application rate of 45 lb N/acre is consistent among all conventional, pure-line cultivars and soil textural classes (Roberts and Hardke, 2015). The current recommendation for midseason N application to occur from BIE to 0.5-inch IE has not been updated for nearly 20 years (Wilson et al., 1998). Due to the introduction of several new rice cultivars since the last midseason N timing study was conducted, new studies have been initiated in order to determine how recently released conventional, pure-line rice cultivars respond to midseason N application and the optimal application timing window.

Recent research has indicated some of the new cultivars do not consistently respond to midseason N application, particularly when an adequate rate of preflood N has been applied. Furthermore, the results of recent studies indicate, when midseason N application produces a grain yield response, the midseason N application time window may be wider and/or later than the week between BIE and 0.5-inch IE as suggested by Wilson et al. (1998). Results of a 2011 midseason N application study indicated a positive influence on rice grain yield when midseason N was applied from BIE to BIE + 14, while BIE + 21 days was not tested (Norman et al., 2012). The 2012 study indicated midseason N applied from BIE to BIE + 21 days significantly increased rice grain yield at two locations, while none of the midseason N application timings resulted in a yield increase at the third location (Norman et al., 2013a). Similarly, the 2013 study showed midseason N applications from BIE to BIE + 21 days generally increased grain yield for both preflood N rates at the University of Arkansas System Division of Agriculture's Northeast Research and Extension Center (NEREC) and Rice Research and Extension Center (RREC), while no midseason N application timings produced a yield response at the Pine Tree Research Station (PTRS) with the greater preflood N rate (Norman et al., 2014). Consequently, the midseason N application timing study was continued in 2015 to further clarify the impact of midseason N applied at four times from BIE to BIE + 21 days on the grain yield of rice based on two preflood N application rates. The two conventional, pure-line rice cultivars selected for the 2015 study were the semidwarf, long-grain cultivar Mermentau from Louisiana and the short stature, long-grain cultivar Roy J from Arkansas.

PROCEDURES

The study was conducted in 2015 at the RREC, near Stuttgart, Ark., on a DeWitt silt loam and the NEREC, Keiser, Ark., on a Sharkey clay. The two conventional,

pure-line rice cultivars chosen for the study were the Louisiana long-grain, semidwarf Mermentau and the Arkansas long-grain, short stature cultivar Roy J. Two preflood N rates were utilized at each location along with four midseason N application timings. Preflood N application rates of 85 and 105 lb N/acre were used at the RREC, while larger rates of 115 and 135 lb N/acre were used on the clay soil at the NEREC. The midseason N rate was 45 lb N/acre at both locations and was applied at BIE, BIE + 7 days, BIE + 14 days, or BIE + 21 days. Additional treatments were a control, or no midseason N application, and a single preflood N application of 130 and 160 lb N/acre at the RREC and NEREC, respectively. All treatments were replicated four times at each location. Preflood N was applied onto dry soil within 24 hours prior to flood establishment and midseason N applications occurred directly into the floodwater.

The rice was drill-seeded in plots 9 rows wide and 15 ft in length with row spacing of 7 in. at a rate of 73 lb/acre on the silt-loam soil at the RREC and 91 lb/acre on the clay soil at the NEREC. Rice was seeded at the NEREC on 4 May and emerged on 20 May, the preflood N was applied on 18 June, and the BIE application occurred on 8 July and 16 July for the cultivars Mermentau and Roy J, respectively. Rice was seeded at the RREC on 1 May and emerged on 10 May, the preflood N was applied on 3 June, and the BIE application occurred on 22 June and 26 June for the cultivars Mermentau and Roy J, respectively. A permanent flood was established at both locations the day after preflood N application when the rice was at the 5- to 7-leaf stage and maintained until the rice reached maturity. The center 5 rows of each plot were harvested at maturity, the moisture content and weight of grain were determined, and yields were calculated based on 12% moisture and a 45-lb bushel weight.

Treatments were arranged in a four replicate randomized complete block factorial design with 2 cultivars × 2 preflood N rates × 4 midseason N application timings. A control with no midseason N application and a single preflood N application treatment were included, each with four replications at both locations. Analysis of variance was performed on the grain yield data utilizing SAS v. 9.4 (SAS Institute Inc., Cary, N.C.). When necessary, differences among means were compared using Fisher's protected least significant difference (LSD) procedure at a $P = 0.05$ probability level.

RESULTS AND DISCUSSION

It should be noted that there were some issues at the NEREC that impacted the results. We had difficulty maintaining the flood due to seepage through the levees and there was bird damage to the plots that increased the variability of the data and probably affected the mean grain yields.

Analysis of variance P values for the studies indicated there were no significant ($P = 0.05$) three-way interactions of cultivar × preflood N rate × midseason N timing or two-way interactions of the treatments on grain yield at either of the two locations (Table 1). There were, however, significant ($P < 0.05$) main effects of cultivar, preflood N rate, and midseason N timing on rice grain yield at both the NEREC and RREC.

At both locations, averaged across preflood N rate and midseason N application timing, the cultivar Roy J outyielded Mermentau by 21 bu/acre at the NEREC and the

RREC (Table 2). Averaged across cultivar and midseason N application timing, the single preflood N application at both locations produced greater grain yields than the two-way split application at the lower preflood N rates and similar yields to the two-way split application at the larger preflood N rates (Table 3). Additionally, the two-way split with the larger preflood N rate increased grain yields compared to the two-way split with the smaller preflood N rate at the RREC, but not at the NEREC.

Averaged over cultivar and preflood N rate at the NEREC, the single preflood N application and BIE + 21 days midseason N application resulted in greater grain yields than the control (no midseason N application); however the three earlier midseason N application timings (BIE, BIE + 7, and BIE + 14 days) did not produce different grain yields than the control, the single preflood application, or the BIE + 21 days midseason application timing (Table 4). At the RREC, averaged over cultivar and preflood N rate, midseason N application increased grain yield over the control when applied at BIE + 7, BIE + 14, or BIE + 21 days, but not when applied at BIE. Rice grain yields were greatest at the RREC and did not differ among the single preflood N application and the two-split when the midseason N was applied at BIE + 14, or at BIE + 21 days.

SIGNIFICANCE OF FINDINGS

A single preflood N application resulted in equal to or greater grain yields than when N was applied in a two-way split application at both locations. On the clay soil at the NEREC, midseason N application only resulted in a grain yield increase over the control (no midseason N) when applied at BIE + 21 days; whereas, on the silt-loam soil at the RREC, midseason N application produced a yield increase over the control when applied at BIE + 7, BIE + 14, or BIE + 21 days. Grain yield increased as the midseason N was delayed at the RREC, but not at the NEREC. The general trend of increasing grain yield as midseason N application is delayed past BIE, up to 21 days, observed at the RREC has been reported in previous studies (Norman et al., 2012; 2013a; 2014). The 2015 results coupled with results from previous studies has led to a change in the recommendation for midseason N application timing. The new recommendation is the midseason N application should be applied no earlier than BIE and at least 3 weeks after the preflood N application; both of these conditions have to be met to obtain the full grain yield benefit from the midseason N application. Future research will help determine how late midseason applications should occur in new cultivars and how wide the application time window is in order to optimize midseason N application timing to ensure maximum grain yield benefits.

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Table 1. Analysis of variance *P* values for rice grain yield as affected by rice cultivar, preflood N rate, and midseason N timing at the Northeast Research and Extension Center (NEREC) and Rice Research and Extension Center (RREC) during 2015.

Source	NEREC	RREC
Cultivar (cult)	<0.0001	<0.0001
Preflood N rate (pfn)	0.0164	<0.0001
Midseason N timing (msn timing)	0.0344	<0.0001
Cult × pfn rate	0.2081	0.8711
Cult × msn timing	0.6047	0.4343
Pfn rate × msn timing	0.0729	0.4095
Cult × pfn rate × msn timing	0.1105	0.5884

Table 2. Influence of rice cultivar, averaged across preflood N rate and midseason N timing, on rice grain yield at the Northeast Research and Extension Center (NEREC) and the Rice Research and Extension Center (RREC) during 2015.

	Grain yield	
Cultivar	**NEREC**	**RREC**
	---------- (bu/acre) ----------	
No MS N	133 e	161 c
Mermentau	151 b†	149 b
Roy J	172 a	170 a
$LSD_{0.05}$‡	6.6	3.7

† Values in the same column followed by different letters are significantly different ($P < 0.05$).
‡ LSD = least significant difference.

Table 3. Influence of preflood N rate, averaged across midseason N timing and cultivar, on rice grain yield at the Northeast Research and Extension Center (NEREC) and the Rice Research and Extension Center (RREC) during 2015.

	Grain yield	
Preflood N rate	**NEREC**	**RREC**
	---------- (bu/acre) ----------	
85†	-----	154 b
105†	-----	163 a
130‡	-----	166 a
115†	156 b§	-----
135†	166 ab	-----
160‡	168 a	-----
$LSD_{0.05}$¶	10.9	5.9

† 45 lb N/acre applied at midseason.
‡ Single preflood N fertilizer application with no midseason N.
§ Values in the same column followed by different letters are significantly different ($P < 0.05$).
¶ LSD = least significant difference.

Table 4. Influence of midseason (MS) N application timing, averaged across preflood N rate and cultivar, on rice grain yield at the Northeast Research and Extension Center (NEREC) and the Rice Research and Extension Center (RREC) during 2015.

	Grain yield	
MS N timing	**NEREC**	**RREC**
	---------- (bu/acre) ----------	
No MS N	152 b[†]	149 c
BIE[‡]	162 ab	154 bc
BIE + 7d	161 ab	158 b
BIE + 14d	163 ab	164 a
BIE + 21d	166 a	170 a
SPF[§]	168 a	166 a
$LSD_{0.05}$[¶]	12.0	6.7

[†] Values in the same column followed by different letters are significantly different ($P < 0.05$).
[‡] BIE = beginning internode elongation.
[§] SPF = single preflood fertilizer application of 130 lb N/acre at RREC; 160 lb N/acre at NEREC.
[¶] LSD = least significant difference.

Summary of Nitrogen Soil Test for Rice (N-STaR) Nitrogen Recommendations in Arkansas During 2015

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ABSTRACT

Seeking to fine-tune nitrogen (N) fertilizer application, increase economic returns, and decrease environmental N loss, some Arkansas farmers are turning away from blanket N recommendations based on soil texture and cultivar and using the Nitrogen Soil Test for Rice (N-STaR) to determine their field specific N rates. First introduced in 2010, Roberts et al. (2010) correlated direct steam distillation (DSD) results from 18-inch depth silt loam soil samples to plot-scale N response trials and subsequently performed field-scale validation. The N-STaR has since been correlated for use on clay soils, using a 12-inch depth soil sample, both at small-plot and field scale validation, and has been offered to the public since 2013. To summarize the samples submitted to the University of Arkansas System Division of Agriculture's N-STaR Soil Testing Lab during 2015, samples were categorized by county and soil texture. Samples were received from 19 Arkansas counties, with Mississippi county and Arkansas county submitting the largest number of fields, with 41 and 31 fields respectively. The total samples received were from 68 silt loam fields and 49 clay fields. The N-STaR N-rate recommendations for these samples were then compared to the producer's estimated N rate, the 2015 Recommended Nitrogen Rates and Distribution for Rice Cultivars in Arkansas, and the standard Arkansas N-rate recommendation of 150 lb N/acre for silt loam soils and 180 lb N/acre for clay soils and divided into three categories and categorized based on a decrease in recommendation, no change in recommended N rate, or an increase in the N-rate recommendation. County, much like in 2013 and 2014, was found to be a significant factor ($P < 0.0001$) in all three comparisons when N-STaR called for a decrease in N rate suggesting that some areas of the state may have higher residual N not accounted for in the other N-rate recommendation strategies when compared to N-STaR. Soil texture was a significant factor in fields where N-STaR proposed a decreased N rate in the cultivar recommendation comparison ($P < 0.05$) and the standard N rate comparison ($P < 0.0005$), and was also a significant factor ($P < 0.05$) in fields for which N-STaR revealed an N rate increase in the producer's estimate comparison.

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INTRODUCTION

In the past, nitrogen (N) fertilizer recommendations for rice in Arkansas were based on soil texture, cultivar, and previous crop; often resulting in over-fertilization which can decrease possible economic returns and increase environmental N loss (Khan et al., 2001). For years researchers tried to develop a soil-based N test that would allow them to better predict the actual N feretilizer needs for a particular field, and finally in 2010 researchers at the University of Arkansas System Division of Agriculture expanded upon previous research at the University of Illinois which used organic-N content in the form of amino sugars to predict corn response to N fertilizer (Mulvaney et al., 2006). University scientists correlated several years of plant-available N estimates from direct steam distillation (DSD) results obtained from 18-inch depth soil samples, equivalent to rice rooting depth on a silt loam soil (Roberts et al., 2009), to plot-scale N fertilizer 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 soil N mineralization rate and one of the highest and consistent N use efficiencies of any cropping system, therefore lending itself to a high correlation of soil mineralizable N to grain yield response (Roberts et al., 2011). After extensive field testing, the Nitrogen Soil Test for Rice (N-STaR), became available to the public for silt loam soils in 2012 with the initiation of the University of Arkansas N-STaR Soil Testing Lab in Fayetteville, Ark. Later, researchers correlated DSD results from 12-inch depth soil samples to N fertilizer response trials on clay soils (Fulford, 2013), and N-STaR rate recommendations became available for clay soils in 2013.

PROCEDURES

In an effort to summarize the effect of the N-STaR program in Arkansas, samples submitted to the University of Arkansas System Division of Agriculture's N-STaR Soil Testing Lab during 2015 were categorized by county and soil texture. The N-STaR N-rate recommendations for these samples were then compared to the producer's estimated N rate if supplied on the N-STaR Soil Test Laboratory Soil Sample Information Sheet, the 2015 Recommended Nitrogen Rates, and Distribution for Rice Cultivars in Arkansas (Roberts and Hardke, 2015), or to the standard Arkansas N-rate recommendation of 150 lb N/acre for silt loam soils and 180 lb N/acre for clay soils, and 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 was analyzed using JMP 12 (SAS Institute, Inc., Cary, N.C.).

RESULTS AND DISCUSSION

Samples were received from 118 fields which represented 30 farmers across 19 Arkansas counties. Mississippi County and Arkansas County, ranked 15th and 3rd in

planted acres (USDA-FSA, 2015), and evaluated the largest number of fields, with 41 and 31 fields, respectively. The samples received were from 68 silt loam fields and 49 clay fields (Table 1). There were only four farmers that sent samples for more than five fields, the average number of fields submitted per farmer was 3.93, with 16 farmers only submitting samples from one field. There were eight farmers who submitted samples in 2015 that also submitted samples in 2014.

Planted rice acreage was down from 1.486 million acres in 2014 (Hardke, 2015) to approximately 1.280 million in 2015 with close to 270,000 prevented acres (USDA-FSA, 2015) most likely due to excessive rains at critical planting times. The N-STaR sample submissions for 2015 mirrored the same trend and were significantly down from the 233 fields submitted in 2014 most likely because of the very wet spring and the inability to sample wet fields. Sample submission by county did not reflect the planted acre estimates for 2015 with Poinsett and Lawrence counties having the highest estimates (USDA-FSA, 2015) yet only submitting samples for seven and one field, respectively.

County ($P < 0.0001$) and soil texture ($P < 0.0005$) were found to be significant factors in the fields with a decrease in N fertilizer rate when the N-STaR recommendation was compared to Arkansas' standard N-rate recommendation of 150 lb N/acre for silt loam soils and 180 lb N/acre for clay soils. This suggests that areas of the state may be prone to N savings potential due to cropping systems and soil series (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 there were no clay fields that resulted in an increased N rate in this comparison (Table 1). Of the fields in this comparison, there was a decrease in the N recommendation for 105 fields (89% of the 118 fields submitted) with an average decrease of 38.6 lb N/acre. No change in N recommendation was found for four fields, while nine fields had an increase in N recommendation (8%), with an average increase of 9.3 lb N/acre.

Eleven of the submitted fields had no estimated N fertilizer rate specified on the N-STaR Sample Submission Sheet and were excluded from the comparison of the N-STaR recommendation to the farmer's estimated N rate. Of those compared, there was a decrease in the N recommendation for 59 fields (~55% of the remaining 107 fields submitted) with an average decrease of 29.7 lb N/acre (Table 1). No change in N recommendation was found for three fields, while 45 fields had an increase in N recommendation (42%), with an average increase of 17.9 lb N/acre. Soil texture was found to be a significant factor ($P < 0.05$) for the fields that resulted in an increase from the producer's estimate to the N-STaR recommendation but was not significant in the fields that resulted in a decrease in N rate. The difference in significance may be due to soil texture variability, soil texture classification errors, and the differences in sample depth and the N-STaR calculations for the two soil textures. The N-STaR recommendations continue to be largely dependent on proper sampling depth for the respective soil texture and the farmer's classification of his field. County was found to be a significant factor in fields that showed a decrease in N-rate recommendation ($P < 0.0001$), but was not a significant factor for fields that called for an increase in N-rate recommendation (Table 2).

When the N-STaR recommendation was compared to the 2015 Recommended Nitrogen Rates and Distribution for Rice Cultivars in Arkansas (Roberts and Hardke, 2015), cultivar recommendations were adjusted for soil texture as recommended by adding 30 lb N/acre for rice grown on clay soils and then compared to the N fertilizer rates determined by N-STaR. The 21 fields that did not list a cultivar on the N-STaR Sample Submission Sheet were excluded from this comparison. There was a decrease in the N fertilizer recommendation for 79 fields (81% of the 97 fields) with an average decrease of 33 lb N/acre (Table 3). No change in N recommendation was found for two fields, while 16 fields had an increase in N recommendation (16%), with an average increase of 15 lb N/acre. County ($P < 0.0001$), soil texture ($P < 0.05$), and cultivar ($P < 0.0005$) were all significant factors in the fields exhibiting a decrease in N rate suggesting that N rates for some cultivars may be overestimated for certain areas of the state or soil textures. However, no factors were found to be significant in the fields which resulted in an increase in N rate.

SIGNIFICANCE OF FINDINGS

These results continue to show the importance 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 ballpark estimations for N rates, but field-specific N rates continue to offer the best estimate of the N fertilizer needed for each particular field no matter soil texture or cultivar selection. 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.

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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 2015 recommended N rates for rice cultivars in Arkansas based on soil texture.

Soil texture	Number of fields submitted	Recommendation				
		Decreased N-STaR		Increased N-STaR		No change
		Fields	Mean N decrease	Fields	Mean N increase	
		(no.)	(lb N/acre)	(no.)	(lb N/acre)	
Standard soil texture						
Clay	49	48	43.8	-	-	1
Silt Loam	68	57	34.2	9	9.3	3
Total	118	105	38.6	9	9.3	4
Producer estimate						
Clay	44	19	27.6	23	21.1	2
Silt Loam	63	40	30.8	22	14.5	1
Total	107	59	29.7	45	17.9	3
Cultivar						
Clay	40	38	37.8	-	-	2
Silt Loam	57	41	28.3	16	14.9	-
Total	97	79	32.8	16	14.9	2

Table 2. Distribution and change in nitrogen (N) fertilizer rate compared to the producer's estimated N rate by county[a].

Soil texture	Number of fields submitted	Recommendation				
		Decreased N-STaR		Increased N-STaR		No change
		Fields	Mean N decrease	Fields	Mean N increase	
		(no.)	(lb N/acre)	(no.)	(lb N/acre)	
Arkansas	30	18	-27.8	11	15.8	1
Ashley	1	-	-	1	30.0	-
Chicot	1	1	-70.0	-	-	-
Clay	4	2	-25.0	2	22.5	-
Cross	1	1	-10.0	-	-	-
Desha	2	2	-12.5	-	-	-
Independence	1	1	-45.0	-	-	-
Lawrence	1	-	-	1	10.0	-
Lee	1	-	-	1	5.0	-
Lonoke	5	5	-62.0	-	-	-
Mississippi	40	16	-20.3	22	19.1	2
Phillips	2	2	-30.0	-	-	-
Poinsett	7	7	-40.0	-	-	-
Prairie	3	1	-15.0	2	25.0	-
Randolph	2	-	-	2	10.0	-
St. Francis	2	2	-12.6	-	-	-
White	4	1	-40.0	3	16.7	-
Total	107	59	-29.7	45	17.9	3

[a] Eleven 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 nitrogen (N) fertilizer rate compared to the 2015 recommended N rates for rice cultivars in Arkansas by cultivar[a].

		Recommendation				
		Decreased N-STaR		Increased N-STaR		
Soil texture	Number of fields submitted	Fields	Mean N decrease	Fields	Mean N increase	No change
		(no.)	(lb N/acre)	(no.)	(lb N/acre)	
Caffey	8	6	-22.5	2	12.0	-
CL 111	5	5	-42.0	-	-	-
CL 151	10	7	-32.9	3	21.7	-
CLXL 729	1	1	-20.0	-	-	-
CLXL 745	4	1	-100.0	2	12.5	1
Francis	1	1	-50.0	-	-	-
Jupiter	6	5	-46.0	1	5.0	-
Lakast	17	17	-20.0	-	-	-
Mermentau	1	-	-	1	10.0	-
Roy J	15	8	-23.8	6	15.8	1
XL 753	29	28	-38.9	1	15.0	-
Total	97	79	-32.8	16	14.9	2

[a] Twenty-one fields did not list a cultivar on their N-STaR Sample Submission Sheet and were excluded from the analysis.

Fig. 1. Percent and mean decrease and increase in N-STaR nitrogen (N) fertilizer rate recommendation by county compared to the standard N fertilizer rate recommendation.

Impact of Storage Duration, Temperature, and Moisture Content on Mold Growth on Hybrid Rice

G.G. Atungulu[1] and S. Thote[1]

ABSTRACT

There is a need to determine kinetics of mold growth on rough rice during storage at various temperatures and moisture contents (MCs) and to delineate conditions that effectively mitigate mycotoxin contamination of the grain. The objective for this study was to simulate conditions of delayed drying and prolonged storage of rough rice and to characterize kinetics of mold growth for hybrid rice at different temperatures and MCs. Long-grain hybrid rice cultivars (XL753 and CL XL745) conditioned to four different MCs (12.5%, 16.0%, 19.0%, and 21.0% wet basis) were stored in sealed containers at temperatures ranging from 45 °F (10 °C) to 104 °F (40 °C) for a period of 16 weeks. For both cultivars, a direct relationship between mold counts and MC was observed; as the MC level increased, the mold counts increased; whereas more complex trends were observed for the effect of temperature and the duration of storage on mold growth. The study concludes that long-grain hybrid rough rice could be stored at low MC levels and moderate temperatures for up to 6 weeks without any change in the mold growth profile. However, storing the rice at high MC (>17%) for more than 8 weeks, especially at higher temperatures should be avoided.

INTRODUCTION

The main factor contributing to spoilage of rice is microbial development (Skyrme et al., 1998; Ranalli and Howell, 2002; Atungulu et al., 2014). In particular, mold contamination poses the greatest problem to rice producers, processors, and consumers. Depending on stress conditions, which may include rice kernel physical characteristics, moisture content (MC), storage temperature, and relative humidity, mold harbored on rice may produce mycotoxins. Mycotoxins, especially aflatoxin, are known carcinogens that pose health hazards to consumers of rice and rice co-products. Microbial contamination of rice may lead to kernel discoloration and undesirable quality, appearance, flavor changes, and other problems such as weakened kernels, resulting in breakage and economic loss (Sahay and Gangopadhyay 1985; Singaravadivel and Raj,

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1983; Phillips et al., 1988; Misra and Vir, 1991). According to Frazier and Westhoff (1967), the spores of storage molds have optimum temperature and relative humidity ranges for development. When the conditions for growth of toxigenic mold are met, some toxigenic molds such as *Aspergillus flavus* may produce aflatoxin (Frazier and Westhoff, 1967; Atungulu et al., 2014; Richard et al., 2003; Lacey and Magan, 1991).

Previous research work focused on characterizing microflora on rice in general (Skyrme et al., 1998; Ranalli and Howell, 2002). However, hybrid rice has a pubescent characteristic which may predispose it to harbor and support mold growth in a different manner when compared to non-pubescent rice. With increased concerns for food security, there is a crucial need to conduct specific research to address the kinetics of fungal mold growth in hybrid rice. Results from such research are vital for implementation of specific postharvest management practices that target the increasingly popular hybrid rice cultivars. This study endeavors to provide useful information regarding prevalence of mold during different storage conditions that can help determine the optimum timeframe and conditions for storage of hybrid rice to not only reduce the economic impact of spoilage due to mold contamination, but also to mitigate the health risks posed by toxigenic molds. The specific objectives for this study were to (1) determine the kinetics of mold growth on long-grain hybrid rice at different MCs and storage temperatures, and (2) determine the optimum conditions for mold growth.

PROCEDURES

Samples

Two long-grain, hybrid rice cultivars planted in Arkansas in 2014 were chosen for this study, CLXL745 from Running Lake Farms near Pocahontas, Ark., and XL753, from the University of Arkansas System Division of Agriculture's Northeast Research and Extension Center near Keiser, Ark. The rice samples were cleaned to remove chaff and foreign matter and then conditioned to the set MC levels (12.5%, 16%, 19%, and 21%). After conditioning the rice to the set MC levels, the rice samples were immediately stored in individual glass jars to prevent significant alterations of their initial MCs and then transported to five separate environments with temperatures set at 45 °F, 59 °F, 68 °F, 80.6 °F, and 104 °F (7.2 °C, 15 °C, 20 °C, 27 °C, and 40 °C). The equipment to generate environments used consisted of a combination of two parameter generation and control (PG&C) units, one refrigerator, one equilibrium moisture content (EMC) control chamber, and one incubator. The samples were stored for a period of up to 16 weeks with samples retrieved at an interval of every 2 weeks. The experiment design is illustrated in Table 1.

The temperature was monitored by placing two temperature sensors (HOBOTM, Onset Computer Corporation, Bourne, Mass.) in each environment. The MC of each sample was measured by placing a 0.53 oz (15 g) sample into a 266 °F (130 °C) convective oven (Shellblue, Sheldon Mfg., Inc., Cornelius, Ore.) for 24 hours followed by cooling in a desiccator for at least one half hour (Jindal and Siebenmorgen, 1987). Table 2 provides the MC values obtained using the method described above.

Microbial Analysis

The AOAC method 997.02 (2002) for the 3M Petrifilm Mold Count Plates (3M Microbiology Product, Minneapolis, Minn.) was used to determine the rough rice total (ground sample) microbial counts which were expressed in terms of colony forming units (CFU) per gram of the sample. The suspensions were prepared by masticating the rice samples at two different settings (Silver Panoramic, iUL, S.A., Barcelona, Spain). The masticator was set at 240 s and 0.5 stroke/s, allowing the rice samples to be pulverized into powder for total microbial load analysis. The successive dilutions of 10^{-4} to 10^{-7} concentration were made by mixing 1 mL of the original mixture with 9 mL of phosphate-buffered dilution water and plated. After the recommended incubation period of 120 h, the CFUs on each plate were calculated using the following formula:

$$T_{cfu} = \frac{P_{CFU}}{D_r} \qquad \text{Eq. 1}$$

where, T_{cfu} is total CFUs per gram of rice (CFUs/g), P_{CFU} is CFUs counted on plate per gram of rice (CFUs/g), and D_r is dilution factor.

For the studied rice samples, preliminary results showed that yeast counts were very low with nearly none detected even with 10^{-10} dilution. Therefore, yeast count was not reported in this research.

Statistical Analysis

Linear regression, analysis of variance, Student's *t* test (least significant difference test), and the Tukey honest significant difference tests were performed with statistical software (JMP v. 12.0.0, SAS Institute, Inc., Cary, N.C.). Level of significance (*P*) was set at 5% for comparing means. Table 3 gives the *P* values and degrees of freedom associated with the three factors studied.

RESULTS AND DISCUSSION

Interaction - Week Number, Temperature, Moisture Content (MC%)

Since the three-way interaction between duration of storage (week number), temperature, and MC was significant (Table 3), the analysis for all three terms was performed together for each cultivar. Figure 1a gives five separate contour plots for the cultivar, CLXL745, showing the distribution of mold counts ($\log_{10}$ CFU/g) over the weeks (y-axis) for various MC levels (x-axis) for each of the storage temperature conditions. For all five temperatures, the contour plots show that less than (or equal to) 6.0 $\log_{10}$ CFU/g of mold were detected for most of the samples. The other distinguishing characteristic revealed by observing all five of the plots was that below 17% MC, the mold growth remained consistently at or below 6.0 $\log_{10}$ CFU/g. The trends observed in these plots suggest that as storage temperature rises, the mold contamination peaks at

about 8 weeks for higher MC samples, and begins dropping after week 12. The steady fall in CFUs detected for increasing temperatures suggests that at lower MC, higher temperature conditions are not conducive to the proliferation of mold.

Similarly, figure 1b shows contour plots for the cultivar XL753. The trends observed are very similar to those observed for CLXL745, except the density and area occupied by the dark contours (greater than or equal to 7.0 $\log_{10}$ CFU/g) were smaller for temperatures below 80.6 °F (27 °C). However, the same trend of increased mold growth was observed for samples above 17% MC and between weeks 6 and 12.

Moisture Content (MC %)

The difference between the molds detected for the different MC levels for the two cultivars was also significant (Table 3). Figure 2 plots the average mean ($\log_{10}$ CFU/g) versus the MC level for cultivars CLXL745 and XL753. The trend observed from these two curves supports the trends observed from the contour plots. For both cultivars, the mold counts for the two lower MC levels are significantly lower than the two higher MC levels ($P < 0.0001$ for both). Additionally, for cultivar CLXL745, the mold counts for MC = 21.1% are significantly higher than MC = 18.8%. However, no difference was detected between the mold counts for MC = 20.8% and MC = 20.3% for cultivar XL753. For both cultivars, a direct relationship between mold counts and MC was observed; as the MC level increased, the mold counts increased.

SIGNIFICANCE OF FINDINGS

The findings from this study provide baseline information which is very helpful in modeling kinetics of microbial growth during rice storage. The information may be useful to guide decisions on drying and storage conditions, especially of hybrid rice cultivars, to avoid mold growth leading to mycotoxin contamination.

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Table 1. Conceptual illustration of the experiment design. The experiment was set up as a full-factorial design with Week 0 and moisture content = 12.5 % (wet basis) serving as the control conditions.

Cultivar	Moisture content	Temperature	Storage duration
	(% wet-basis)		[°F (°C)]
CLXL745	12.5	45 (10)	Week 0
XL753	16	59 (15)	Week 2
	19	68 (20)	Week 4
	21	80.6 (27)	Week 6
		104 (40)	Week 8
			Week 10
			Week 12
			Week 16

Table 2. Difference between percent moisture content (MC%) values set during the design stage and the actual, experimentally measured MC% values.

	Actual moisture content	
Set value	XL745	XL753
	----------(MC %) ----------	
12.5	12.7	12.3
16	16.1	17.4
19	18.8	20.3
21	21.1	20.8

Table 3. Summary of the *P* values from the analysis of variance for the effect of week number, temperature, and percent moisture content (MC%) by cultivar on mold counts.

		Prob > F	
Factor	df[a]	CLXL 745	XL753
Week number	7	*0.7124*	0.0006
Temperature	4	*0.1387*	*0.4442*
Week number × temperature	28	*0.1465*	*0.754*
MC %	3	<.0001	<.0001
Week number × MC %	21	<.0001	<.0001
Temperature × MC %	12	0.0001	<.0001
Week number × temperature × MC %	84	<.0001	<.0001

[a] df = degrees of freedom.

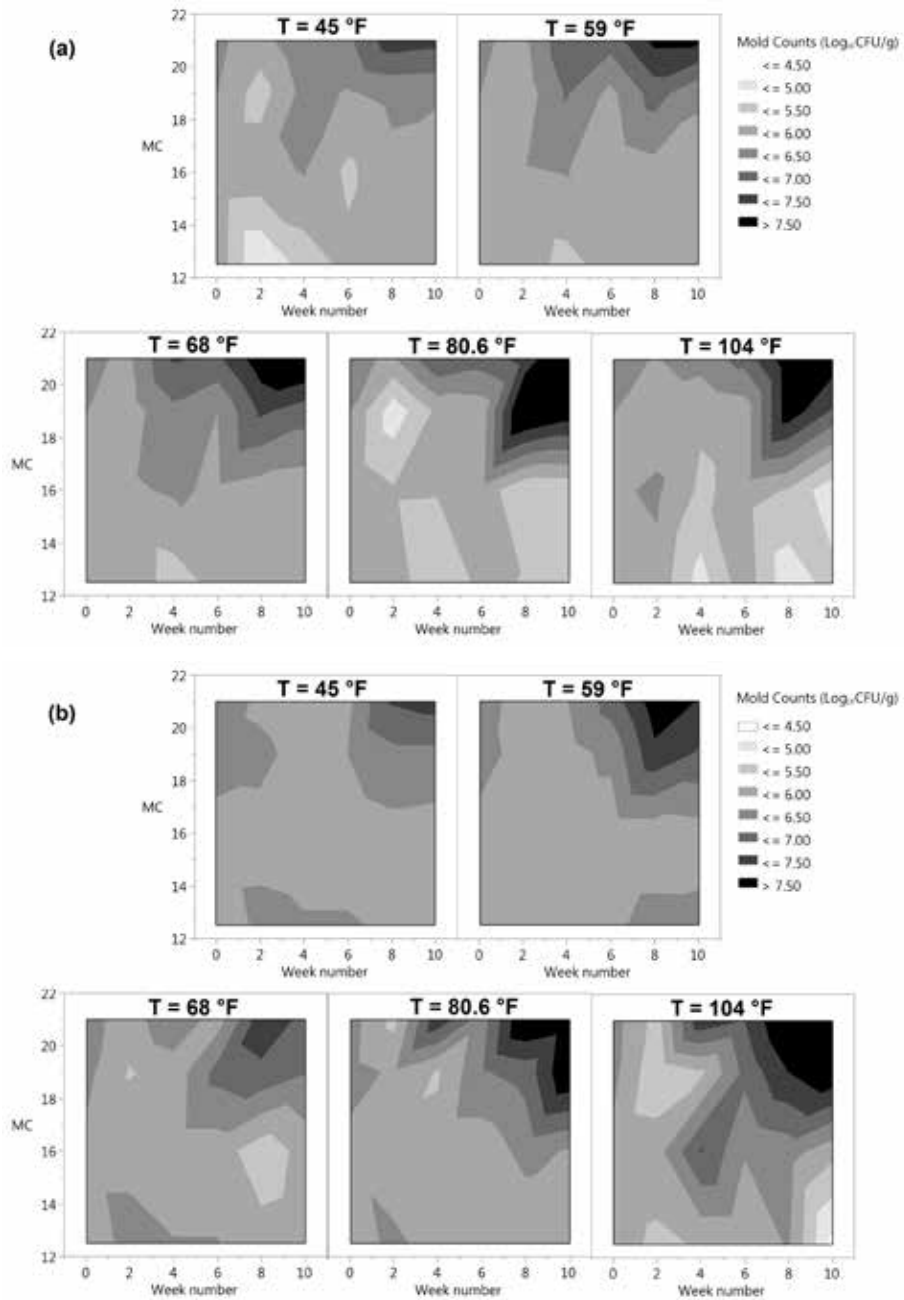

Fig. 1. Contour plots of mold counts [colony forming units (log_{10} CFU)] as influenced by the interaction between storage duration (week number), percent moisture content (MC%) and storage temperature for cultivar XL745 (a) and XL753 (b), respectively.

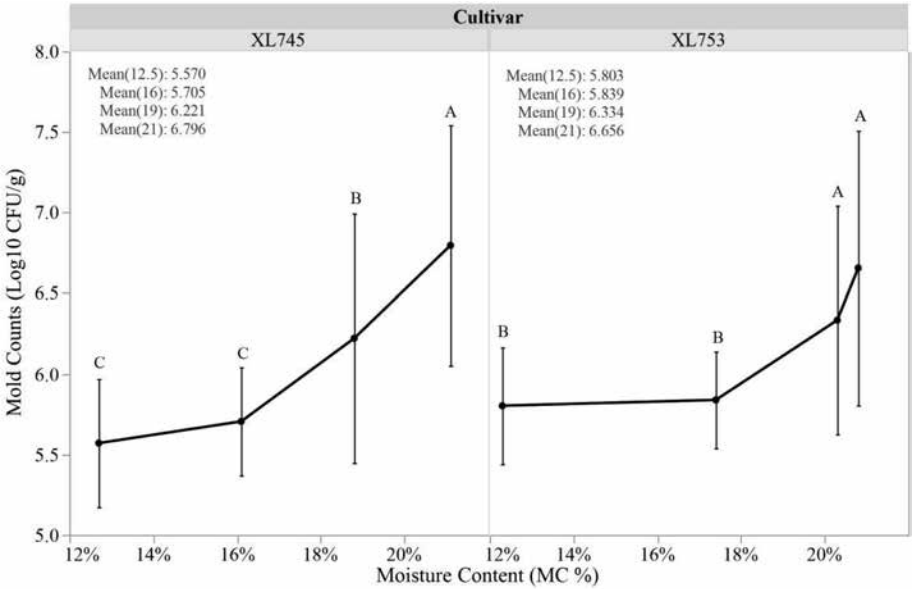

Fig. 2. Relationship between mold counts (log_{10} CFU/g) and percent moisture (MC%) content for the two cultivars, CLXL745 and XL753. Means followed by different letters are significantly different ($P \leq 0.05$) from each other.

Simulation and Validation of On-Farm In-Bin Drying and Storage of Rough Rice

G. G. Atungulu[1] and H. Zhong[1]

ABSTRACT

The objectives for this study were to: (1) determine accurate models for predicting equilibrium moisture content (EMC) of rough rice at set conditions of air temperature and relative humidity (RH); and (2) validate developed mathematical model for predicting rough rice moisture content (MC) and temperature profiles during natural air (NA), in-bin drying and storage. Adsorption and desorption isotherms of long-grain hybrid rough rice cultivar, Clearfield (CL) XL745, at temperatures ranging from 15 °C to 35 °C and RHs of 10% to 90% were determined by using Dynamic Vapor Sorption analysis equipment. Non-linear models were used to determine constants of models for predicting the rough rice adsorption and desorption EMCs. It was determined that the best model to describe the studied rough rice adsorption isotherms was the modified Halsey equation (RMSE = 0.54% MC dry basis), while the modified Chung-Pfost equation (RMSE = 0.91% MC dry basis) was best to describe desorption isotherms. The updated rough rice EMC prediction equations were incorporated into an equilibrium-based finite difference model used to simulate temperature and MC of in-bin rough rice drying at two selected rice growing locations in Arkansas. The model was validated using field experiments that used modern, on-farm bins equipped with sensors for in-bin RH and rough rice temperature measurements. The rough rice MC was calculated using the equilibrium models with inputs of measured RH and temperature data. Analyses were conducted to compare sensor-determined rough rice MC and temperature data to that determined from both the simulation model and from laboratory moisture meter-measurements. The simulation results described the general trends of rough rice sensor-determined MC and temperature profiles well (for MC, mean RMSE = 0.56% MC on a wet basis; for temperature, mean RMSE = 1.77 °C). The rough rice MC data determined by the sensors overpredicted the meter-measured MCs by 4.54% and 7.60%, and the RMSEs were 1.48% MC and 0.73% MC for drying bins located at Burdette and Dermott, Arkansas, respectively. The study generated useful information for predicting rough rice MC and temperature during NA in-bin field drying and storage.

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INTRODUCTION

In-bin drying and storage of rough rice using natural air (NA), if not managed properly, is prone to contamination of rough rice with mycotoxins (e.g., aflatoxin), posing significant public health risks and reducing overall rice quality. The NA drying method involves use of a fan (often more than one) to mechanically push ambient air through a rough rice column, from the bottom to the top of the bin. As the air moves vertically through the rough rice inside the bin, the air "quality" determines whether the rough rice gains or loses moisture. The air "quality", also referred to as the equilibrium moisture content (EMC), defines the capability of the rough rice to hold moisture at set conditions of air temperature and relative humidity (RH). Depending on local weather conditions, the duration required for NA, in-bin drying may not be conducive for timely and complete drying, especially for upper layers of rough rice (Atungulu et al., 2015). It is important to know the extent to which drying with NA in a particular location influences rough rice drying duration to mitigate rice quality reduction, mold growth, and development of mycotoxins.

A field study to obtain NA, in-bin drying kinetics for rough rice would require extensive, time-consuming, and costly experimentation. However, an accurate mathematical model may simplify prediction of the NA, in-bin drying process of rough rice. There is, therefore, a critical need to develop and validate an accurate model that could be used to simulate NA, in-bin drying of rough rice and the effects on rice quality. The model could be used for simulations to provide suitable drying conditions for rough rice at different geographical regions. In the absence of such a model to predict suitable drying strategies, in-bin rough rice drying and storage with NA will be more susceptible to grain quality loss and contamination with toxigenic fungi and their associated mycotoxins, many of which are carcinogenic to humans.

The objectives for this research were to use developed mathematical models to simulate NA, in-bin drying and storage of rice and to validate the results. Specifically, the study: (1) determined accurate models for predicting EMC of rough rice at set conditions of air temperature and RH; (2) incorporated the new EMC models into the developed mathematical models for NA, in-bin drying of rice; and (3) validated the accuracy of the new models to predict moisture content (MC) and temperature profiles of rough rice during NA, in-bin drying at different Arkansas locations by field experiments.

PROCEDURES

Moisture Content Determination

Long-grain rice cultivar Clearfield (CL) XL745, grown at Newport, Ark., was harvested in fall of 2014 at 16% MC. Immediately after harvest, rough rice samples were placed in sterile polyethylene bags, sealed, and stored in a cooler set at 4 °C. The samples were stored in the cooler and retrieved later for experiments. To determine the initial moisture content (IMC) of rice, samples from the bags were retrieved and allowed to equilibrate at room conditions, and then 15 g of the sample was placed into a conductive oven set at 130 °C (Shellblue, Sheldon Mfg., Inc., Cornelius, Ore.). The

sample was kept in the oven for 24 hours, after which it was removed, placed in the desiccator, and allowed to cool for at least one half hour (Jindal and Siebenmorgen, 1987). The adsorption and desorption isotherms of the rough rice samples were determined using Dynamic Vapor Sorption (DVS) analysis equipment [AquaLab Vapor Sorption Analyzer (VSA), Decagon Devices, Inc., Pullman, Wash.].

Rough rice MC during desorption and adsorption versus temperature and water activity (equilibrium RH in decimal) were analyzed using nonlinear regression in JMP Pro v. 12.1.0 (SAS Institute, Inc., Cary, N.C.) to estimate the empirical constants (A, B, and C) of the four rough rice EMC models in Table 1. The main effects of all variables on EMC and statistical parameters were determined using Fit Model JMP Pro v. 12.1.0 (SAS Institute, Inc., Cary, N.C.), and statistical significance (*P*) was set to 0.05. Excel software (Microsoft Office 2013, Microsoft Corp., Redmond, Wash.) was used to calculate the Root Means Square error (RMSE), Nash-Sutcliffe efficiency (NSE), and Percent bias (PBIAS) which were used to evaluate the relationships among meter-measured sample MCs, the sensor-determined MCs, and MCs obtained from simulation output.

Development of Computer Simulation Platform and Mathematical Simulations

A computer simulation program based on the Post-harvest Aeration Simulation Tool - Finite Difference Model (PHAST-FDM), written in Visual Basic.NET (Microsoft Corp., Redmond, Wash.), was modified for use with rough rice (Lawrence et al., 2015). Modifications of the program included development of an interactive Graphical User Interface (GUI), incorporation of updated EMC models of rough rice, addition of functions to calculate percent overdrying and rice dry matter loss (DML), and addition of multiple options for controlling when to end the simulations (Fig. 1). The modified program was used to simulate NA, in-bin drying of rough rice at representative rice-growing locations.

The energy balance applied to a thin rice layer was determined as described by Jindal and Siebenmorgen (1994):

$$c_a T_o + H_o (h_v + c_v T_o) + c_g G_o r + c_w G_o (h_f - H_o) = c_a T_f + H_f (h_v + c_v T_f) + c_g T_f r \qquad \text{Eq. 1}$$

where, c_a is specific heat of dry air (J/kg of dry air/K); c_g is specific heat of grain (J/kg of wet grain/K); c_v is specific heat of water vapor (J/kg of water vapor/K); c_w is specific heat of water (J/kg of water in grain/K); H_o is absolute humidity of air entering the control volume (kg of water/kg of dry air); H_f is absolute humidity of air leaving the control volume (kg of water/kg of dry air); T_o is initial air temperature (°C); T_f is final air and grain temperature (°C); h_v is latent heat of vaporization of water (J/kg of water vapor); G_o is initial grain temperature (°C); and r is grain mass to dry air ratio (kg of wet grain/kg of dry air). On the left side of Eq. 1, the first term represents the energy of the dry air with respect to 1 kg of dry air before air entering the rough rice layer. The second term represents the energy of the water vapor in the air with respect to 1 kg of dry air before air entering the rough rice layer. The third term represents the energy of the wet rough rice layer (percent MC) with respect to 1 kg of dry air before air entering the rough rice layer. It is assumed that the change of the amount of water in the rough

rice is equal to the change of humidity in the air; therefore, the fourth term represents the energy difference of the water which is desorbed or adsorbed by the rough rice with respect to 1 kg of dry air. The three terms on the right side of Eq. 1 correspond to the first three terms of the left side of the equation, and they are for conditions after the air exits the rough rice layer.

The moisture balance applied to a thin rice layer, with the assumption that the mass of water evaporated from the rough rice in the layer is equal to the change in mass of water vapor in the air passing through the layer, was determined as described by Jindal and Siebenmorgen (1994):

$$H_f - H_o = (MC_o - MC_f)\, r / 100 \qquad \text{Eq. 2}$$

$$r = (\rho_g\, d_x) / \rho_a\, v_a\, t \qquad \text{Eq. 3}$$

where, MC_o is initial MC of grain in percentage wet basis; MC_f is final MC of grain in percentage wet basis; t is time interval (s); ρ_a is density of air (kg of air/m^3); ρ_g is density of grain (kg of wet grain/m^3); v_a is velocity of air (m/s); and d_x is layer thickness (m).

Using the exiting air RH and temperature, the rough rice MC in each layer at the end of a time step was determined. The modified Chung-Pfost equation Eq. 4 with constants specified for long-grain hybrid rough rice in adsorption and desorption conditions was used:

$$MC_e - \frac{1}{B} \ln \left[\frac{-(T + C) \ln (RH)}{A} \right] \qquad \text{Eq. 4}$$

where, MC_e is equilibrium moisture content of rough rice in percentage dry basis; RH is relative humidity in decimal; T is temperature (°C); and A, B, and C are empirical constants.

Adsorption and desorption constants (two sets of A, B, and C) for Eq. 4 were determined in this study for long-grain hybrid rice cultivar (CLXL745). Relative humidity, temperature, and partial and saturated vapor pressures of air were determined using (ASABE Standards, 2014):

$$RH = \frac{P_v}{P_s} \qquad \text{Eq. 5}$$

$$P_v = \frac{101325\, {}^{o}H}{0.6219 + H} \qquad \text{Eq. 6}$$

$$P_s = K \times \exp\left(\frac{A + B^{o}T + C^{o}T^2 + D^{o}T^3 + E^{o}T^4}{F^{o}T - G^{o}T^2} \right) \qquad \text{Eq. 7}$$

where, RH is air relative humidity in decimal; P_v is partial vapor pressure of air (Pa); P_s is saturated vapor pressure of air (Pa); H is absolute humidity of air (kg of water/kg of dry air); T is air temperature (°C); K = 22105649.25; A = -27405.526; B= 97.5413; C = -0.146244; D = 0.12558 × 10^{-3}; E = -0.48502 × 10^{-7}; F = 4.34903; G = 0.39381 × 10^{-2}.

Using Eqs. 1 to 7, the temperature and RH of air exiting each rough rice layer and the rough rice temperatures at the end of each time step were determined. A finite difference method was used to determine the time-step solutions of rough rice MC and temperature as well as the intake and exit air conditions in successive layers of the rough rice inside the bin. The rough rice inside the bin was divided into N thin layers (N = 20).

RESULTS AND DISCUSSION

Adsorption and desorption isotherms of long-grain hybrid rough rice cultivar CLXL745 were determined (Table 2). The result showed the average rough rice desorption EMC was higher than the average adsorption EMC, and rough rice EMC significantly increased when air temperature decreased, or air RH increased. Four empirical EMC models (modified Chung-Pfost, modified Halsey, modified Henderson, and modified Oswin) were fitted with actual data, and constants for predicting both adsorption and desorption EMCs were established (Table 3). The modified Halsey and modified Chung-Pfost equations best predicted EMCs of long-grain hybrid rough rice for adsorption and desorption conditions, respectively (Table 3). The modified Chung-Pfost equation and associated adsorption and desorption constants were selected for NA, in-bin drying simulations and model validation performed in this study.

Experiments using on-farm, in-bin drying systems, equipped with sensors for automatic monitoring of grain temperature and RH in the bin, were performed to validate the developed model for NA, in-bin drying of rough rice in Arkansas locations (Table 4). Rough rice MC data determined by field sensors overpredicted the meter-measured MCs by 4.54% and 7.60%, and the root mean square errors (RMSEs) were 1.48% MC and 0.73% MC for drying bins located at Burdette and Dermott, Arkansas, respectively (Table 5).

Simulation results of rough rice MC and temperature from the developed model were compared with field sensor-determined profiles for rough rice drying with equilibrium moisture content natural air (EMC-NA) fan control strategy; the mean RMSEs of rough rice MC and temperature were less than 0.57 ± 0.10% MC and 1.91 ± 0.21 °C, respectively (Table 6); mean Nash-Sutcliffe efficiencies (NSE) of rough rice MC and temperature were greater than 0.68 ± 0.50 and 0.49 ± 0.04, respectively; percent biases (PBIAS) range of rough rice MC were between -3.53% and 5.76%; PBIAS range of rough rice temperature was between -3.96% and 1.78%. These statistical parameters indicated that the simulated rough rice MC and temperature profiles reasonably predicted the rough rice temperature and MC data, determined using field sensors.

SIGNIFICANCE OF FINDINGS

The study validated models for NA, in-bin drying of rough rice, thereby providing new tools for understanding the kinetics of rough rice MC and temperature during on-farm, in-bin drying and storage using natural air; such information is critical to further prediction of rice quality and safety.

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Table 1. Moisture sorption prediction models according to American Society of Biological and agricultural engineers standard D245.6 (2012).

Name of model	Equation†
Modified Chung-Pfost	$MC \times 100 = -\frac{1}{B} \ln \left[-\frac{(T + C) \ln (RH)}{A} \right]$
Modified Halsey	$MC \times 100 = \left[-\frac{\exp(A + B * T)}{\ln (RH)} \right]^{\frac{1}{C}}$
Modified Henderson	$MC \times 100 = \left[\frac{\ln (1 - RH)}{-A * (T + C)} \right]^{\frac{1}{B}}$
Modified Oswin	$MC \times 100 = (A + B * T) \left(\frac{1 - RH}{RH} \right)^{\frac{-1}{C}}$

† MC is air equilibrium moisture content in decimal dry basis, RH is relative humidity expressed as a decimal and T is temperature (°C). The terms A, B, and C are empirical constants.

Table 2. Equilibrium moisture contents of long-grain hybrid rice cultivar CLXL745 at temperatures ranging from 15 °C to 35 °C and relative humidities ranging from 10% to 90% in desorption and adsorption conditions.

	Temperature (°C)					
	Adsorption EMC†			Desorption EMC†		
Relative humidity	15	25	35	15	25	35
(%)	(% w.b.)‡					
10	11.9 a§ B¶	10.0 ab D	9.0 b D	12.4 a' D'	9.9 b' E'	9.1 b' E'
30	12.3 a B	10.5 ab D	9.5 b D	13.9 a' C'	12.3 b' D'	10.8 c' D'
50	13.3 a B	12.5 a C	12.0 a C	16.3 a' B'	15.0 ab' C'	14.0 b' C'
70	16.1 a A	15.8 a B	15.6 a B	18.8 a' A'	18.5 a' B'	17.3 a' B'
90		22.6 a A	22.3 a A		22.6 a' A'	22.3 a' A'

† EMC = equilibration moisture content.
‡ % w.b.= percent wet basis.
§ For each sorption type and temperature combination, values within individual columns followed by the same lowercase letter are not significantly different.
¶ For each sorption type and relative humidity combination, values within individual rows followed by the same uppercase letter are not significantly different.

Table 3. Constants, root mean square errors (RMSEs), and sums of RMSE (SRMSEs) of Modified Chung-Pfost, Modified Halsey, Modified Henderson, and Modified Oswin equations used for predicting desorption and adsorption isotherms of long-grain rough rice.

Model	Sorption type	Model constants A	Model constants B	Model constants C	RMSE	SRMSE
					---------- (% MC d.b.)† --------	
Modified Chung-Pfost	Desorption‡	861.4998	0.2382	9.6002	0.54	1.86
	ASABE§	579.9479	0.1894	52.1784	0.61	
	ASABE¶	412.02	0.17528	39.016	0.26	
	Adsorption‡	1086.5411	0.2454	29.8549	1.32	
	ASABE§	590.3090	0.1936	55.2229	0.78	
Modified Halsey	Desorption‡	10.9302	-0.0320	3.9053	0.86	1.77
	ASABE§	8.1726	-0.006112	3.3578	1.66	
	Adsorption‡	9.0526	-0.0183	3.4783	0.91	
	ASABE§	8.3821	-0.01029	3.3874	1.45	
Modified Henderson	Desorption‡	8.0518×10^{-7}	3.5691	21.4187	2.34	4.34
	ASABE§	2.9747×10^{-5}	2.1177	79.1993	0.51	
	ASABE¶	4.1276×10^{-5}	2.1191	49.828	0.29	
	Adsorption‡	8.9734×10^{-7}	3.3119	93.1951	2.00	
	ASABE§	3.3900×10^{-5}	2.1226	73.0724	0.69	
Modified Oswin	Desorption‡	17.9920	-0.1104	5.2319	0.79	2.11
	ASABE§	13.1323	-0.02873	3.9156	1.20	
	ASABE¶	14.431	-0.07886	3.137	0.36	
	Adsorption‡	15.0560	-0.0560	4.7226	1.32	
	ASABE§	13.4692	-0.04410	3.9542	1.10	

† % MC d.b. = percent moisture content on a dry basis.

‡ Constants generated using JMP 12.0.0 based on the experimental result of this study for predicting desorption and adsorption isotherms of long-grain hybrid rough rice (cv. CLXL745).

§ Constants generated using JMP 12.0.0 based on the equilibrium moisture content data listed in American Society of Agricultural and Biological Engineers (ASABE) standard D245.6 (2012) for long-grain rough rice (cv. Inga) in desorption and adsorption conditions.

¶ Constants listed in American Society of Agricultural and Biological Engineers (ASABE) standard D245.6 (2012) for long-grain rough rice.

Table 4. Configurations and drying strategies of bins A, B, C, and D.

	Bin A	Bin B	Bin C	Bin D
Bin location	Burdette, Ark.	Dermott, Ark.	Dermott, Ark.	Dermott, Ark.
Sensor locations	Center and side	Center and side	Center and side	Center and side
Bin diameter	14.63 m (48 ft)	14.63 m (48 ft)	14.63 m (48 ft)	14.63 m (48 ft)
The top-most sensor depth	Side: 6.1 m (20 ft)	Side: 6.1 m (20 ft)	Side: 6.1 m (20 ft)	Side: 6.1 m (20 ft)
Center: 7.32 m (24 ft)	Center: 7.32 m (24 ft)	Center: 7.32 m (24 ft)	Center: 7.32 m (24 ft)	
Fan configuration	40 HP 1750 RPM centrifugal fan; 2 fans in parallel	40 HP 1750 RPM centrifugal fan; 2 fans in parallel	30 HP 1750 RPM centrifugal fan; 2 fans in parallel	30 HP 1750 RPM centrifugal fan; 2 fans in parallel
Fan control strategy[†]	EMC-H	EMC-NA	EMC-NA	EMC-NA
Target EMC	12.5% (w.b.)[‡]	12.5% (w.b.)	12.5% (w.b.)	12.5% (w.b.)
Targeted EMC range	N/A	14.5% - 10.5% (w.b.)	13.5% - 10.5% (w.b.)	14.5% - 10.5% (w.b.)
Issues for simulation and validation	Targeted EMC limits changed during the drying period	One fan was off during the first half of drying period	N/A	N/A
Simulation-start date and time	N/A	N/A	26 Sept. 2014 at 12:00 AM	03 Oct. 2014 at 4:00 AM
Simulation-end date and time	N/A	N/A	21 Oct. 2014 at 11:59 PM	27 Oct. 2014 at 11:59 PM
Initial rough rice Temperature[§] (°C)	N/A	N/A	Sensor6=20.44, Sensor5=20.39, Sensor4=21.11, Sensor3=21.61, Sensor2=21.56, Sensor1=22.83.	Sensor6=26.33, Sensor5=26.17, Sensor4=26.11, Sensor3=26.00, Sensor2=24.11, Sensor1=24.94.
Initial rough rice moisture content[§] (%.w.b.)	N/A	N/A	Sensor1=15.32, Sensor2=16.95, Sensor3=16.67, Sensor4=17.96, Sensor5=17.56, Sensor6=16.01.	Sensor1=14.74, Sensor2=16.84, Sensor3=16.38, Sensor4=18.69, Sensor5=19.58, Sensor6=19.53.
Plenum pressure	N/A	N/A	1673.03 Pa (6.71 in H_2O)	1637.07 Pa (6.57 in H_2O)

[†] EMC-H represents equilibrium moisture content controlled air with supplemental heat fan control strategy; EMC-NA represents equilibrium moisture content controlled natural air fan control strategy.

[‡] w.b.=wet basis.

[§] Sensor1 represented the first (bottom) layer, and Sensor2 represented the second layer MC which was 1.22 m (4 ft) above the first layer. Therefore, Sensor6 was 7.32 m (24 ft) from the bottom of the bin.

Table 5. Sensor-determined moisture content (MC) and meter-measured MC data for rough rice in bins A and B; comparison of root mean square errors (RMSEs) and percent biases (PBIASs). Rice in the bin was sampled 1.22 m (4 ft) below the top-most layer surface at the center.

Bin location	Sampling date	In-bin sensor-determined MC data	Meter-measured MC data	RMSE	PBIAS
		----------(%w.b.)†	----------		(%)
Bin A					
Dermott, Ark.	12/10/2014	20.33	19.22	1.48	7.60
	26/10/2014	20.62	19.22		
	9/11/2014	19.64	17.35		
	21/11/2014	14.76	14.24		
Bin B					
Burdette, Ark.	13/9/2014	16.33	15.53	0.73	4.54
	27/9/2014	16.36	16.13		
	11/10/2014	13.83	12.72		
	25/10/2014	13.07	12.62		

† w.b. = wet basis.

Table 6. Statistical parameters [Root mean square errors (RMSEs), Nash-Sutcliffe efficiencies (NSEs) and percent biases (PBIASs)] used to evaluate model performance for bins C and D. (a) comparison of moisture content calculated from sensor data of temperature and relative humidity and simulation, (b) comparison of temperature determined by sensor and simulations.

Layer	1	2	3	4	5	6	Mean
(a) Moisture content comparison							
Bin C							
RMSE (% w.b. MC)†	0.41	0.32	0.64	0.48	0.30	1.07	0.54±0.29‡
NSE	0.60	0.95	0.85	0.94	0.97	0.42	0.79±0.23‡
PBIAS (%)	0.46	-1.43	-3.31	-1.66	-0.73	5.76	2.23±2.00§
Bin D							
RMSE (% w.b. MC)	0.60	0.41	0.53	0.53	0.67	0.67	0.57±0.10‡
NSE	-0.33	0.83	0.83	0.93	0.93	0.91	0.68±0.50‡
PBIAS (%)	3.22	-0.87	-1.98	-1.99	-3.53	-2.65	2.37±0.97§
(b) Temperature comparison							
Bin C							
RMSE (°C)	1.77	1.47	1.55	1.60	1.62	1.47	1.58±0.11‡
NSE	0.81	0.87	0.85	0.83	0.80	0.82	0.83±0.03‡
PBIAS (%)	-1.46	0.06	1.78	0.12	0.17	-3.07	1.11±1.21§
Bin D							
RMSE (°C)	2.28	2.04	1.83	1.82	1.82	1.69	1.91±0.21‡
NSE	0.56	0.48	0.46	0.50	0.50	0.45	0.49±0.04‡
PBIAS (%)	-3.54	-3.96	-2.48	-2.85	-2.83	-2.07	2.96±0.69§

† %w.b. MC = percent wet basis moisture content.

‡ Numbers represent the mean and the standard deviation.

§ Numbers represent the mean and the standard deviation of the absolute value of the PBIAS (mean absolute PBIAS = $\sum_{i=1}^{N} (|Y_i|) / N$).

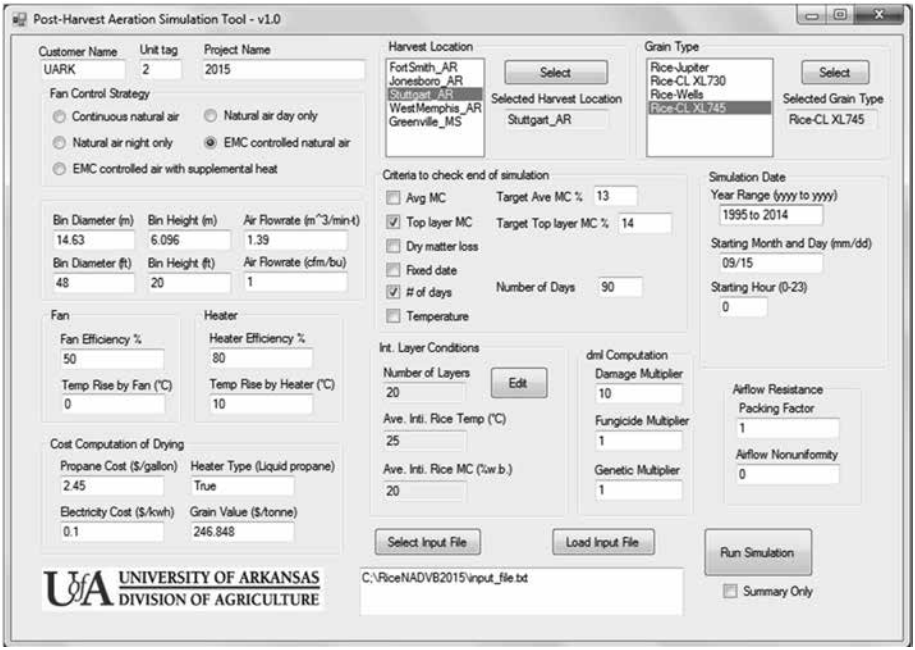

Fig. 1. User interface of a computer program, written in Visual Basic.NET, for simulation of natural air drying of rough rice.

Optimization of Process Parameters in Rough Rice Drying Using Industrial Microwave

G.G. Atungulu[1], G.A. Olatunde[1], D.L. Smith[1], S. Sadaka[2], and S. Rogers[3]

ABSTRACT

The use of industrial microwave (MW) at 915 MHz may have the potential to achieve one-pass rough rice drying. However, it is vital to determine the optimal processing parameters for continuous-flow drying operations that maximize drying throughput and minimize milled rice quality reduction. Therefore, the objective for this study was to quantify the effect of MW energy applied per unit mass of rough rice on moisture, and milled rice quality reduction for a continuous one-pass MW drying operation of rough rice. Freshly harvested, medium-grain rough rice with moisture content of 25% wet basis (w.b.) was used for this study. A portion of the sample was used as control and the remaining was dried in a pilot scale 915 MHz MW for up to 8 minutes drying duration. The rough rice was heated at specific energies of 194, 258, and 322 Btu/lb (450, 600, and 750 kJ/kg) at various rice bed thicknesses of 0.4, 1.2, and 2.0 inches (0.01, 0.03, and 0.05 m). The results showed that moisture removed varied between 6 and 15 percentage points as specific energy increased. Also, increase in bed thickness with increase in specific energy from 194 to 258 Btu/lb (450 to 600 kJ/kg) resulted in reduction in milling yield from 73% to 62%. Head rice yield (HYR) was reduced from 66% to 37% as specific energy increased from 194 to 322 Btu/lb; there were marginal reductions in measured rice fat (0.50% to 0.34%) and protein (6.13% to 5.60%) contents. In conclusion, drying of medium-grain rough rice using a continuous-flow, one-pass MW heating at a specific energy of 194 Btu/lb and bed thickness of 0.4 inches appeared to be most the promising treatment of all the studied conditions.

INTRODUCTION

A convective air drying method is typically used to dry freshly harvested (rough) rice to a safe moisture content (MC) usually 12% to 13% wet basis (w.b.) prior to storage. However, formation of temperature gradient between the core and the surface of

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the kernel causes moisture migration towards the surface of the kernel and could induce tensile stress at the surface and compressive stress at the interior of the kernel (Fan et al., 2000). Stress in the rice kernel causes rice fissuring and degradation of mechanical properties, which ultimately is responsible for the kernel's inability to withstand the processes of hulling and bran removal without breaking. The milled rice is quantified by the head rice yield (HRY) as percentage by mass of those kernels retaining three-fourths or more of their original length, to the original rough rice. Reduction in HRY during milling operation results in economic loss to the farmer. Hence, there is need to explore methods that can be used for drying rough rice without causing reduction in HRY. Microwave (MW) heating may reduce stresses caused by temperature and MC gradients within the rice kernel and potentially improve the rice milling yield because the technology uses volumetric heating method.

Microwave is a form of electromagnetic energy with the frequency range of 300 MHz to 300 GHz and the corresponding wavelengths of 1 mm and 1000 mm (Oghbaei and Mirzaee, 2010). Microwave drying has a volumetric heating characteristics which is unlike the convective heating method; this leads to accelerated increase in temperature at the interior of the kernel (Datta and Davidson, 2000; Gowen et al., 2006; Vadivambal and Jayas, 2007). Microwave drying may offer many advantages over convective drying methods under similar conditions such as high thermal efficiency, and shorter drying time (Ren and Chen, 1998). Heat losses to the surrounding air are much lower since heat generated occurs primarily inside the product. Since energy is not consumed in heating the walls of the apparatus or the environment, operational cost is lower and floor space requirement compared to conventional driers with similar plant capacity is significantly lower (Bouraoui et al., 1994; Chandrasekaran et al., 2013; Jiao et al., 2014; Zhang et al., 2006).

The most commonly used MW energy frequencies for drying/heating purposes are 915 MHz and 2.45 GHz (Oghbaei and Mirzaee, 2010). Domestic MW appliances operate at a frequency of 2.45 GHz, while industrial MW systems typically operate at frequencies of 915 MHz. Industrial MW produces a longer wavelength with more penetrating power than domestic MW (Chandrasekaran et al., 2013). Despite the advantages of MW heating technology, there is no commercial use of MW technology for rice drying in the United States. Few published work on MW rice drying that use 2450 MHz have been reported (Kaasova et al., 2002; Le et al., 2014). Scaling up MW system that operate at 2450 MHz has been a challenge due to associated low penetration depth, non-uniformity of heating, and energy inefficiencies. On a commercial drying level, there is a need to investigate the impact of using industrial MW on rice milling yield, and functional quality indices. The objective for this research was to determine the feasibility of using an industrial-type MW heating system operated at 915 MHz frequency to achieve one-pass rough rice drying with minimum implications on the rice quality.

PROCEDURES

Materials

Freshly harvested medium-grain rough rice (cv. Jupiter), grown in the 2014 rice crop season at Cash, Ark., was procured at initial MC of 23% to 24% w.b. and used for

this study. The samples were cleaned using a dockage equipment (MCi Kicker Dockage Tester, Mid-Continent Industries Inc., Newton, Kan.), and placed in an airtight tub and stored in a laboratory cold room set at 39.2 °F (4 °C) (Koolco, Hialeah, Fla.). At the beginning of the experiments, the samples were retrieved from the cold room, and allowed to equilibrate at room conditions (77 °F) for 24 h before the time of use. The MCs were determined using grain moisture tester (AM 5200, Perten, Kurva, Sweden), which was calibrated according to the American Society of Biological Engineers (ASABE) standard (Jindal and Siebenmorgen, 1987). All reported MCs were on wet basis.

Microwave Heating Treatment

A 915 MHz industrial MW dryer (AMTek Microwaves, Cedar Rapids, Iowa) was used for the experiment (Fig. 1). The system consists of a transmitter, a wave guide and microwave heating zone (oven). The system transmitter is a high-powered vacuum tube that works as a self-excited microwave oscillator converting high-voltage electric energy to microwave radiation. The system waveguide consists of a rectangular pipe through which the electromagnetic field propagated lengthwise; it was used to couple the microwave power from the magnetron into the lab oven. The oven is the internal cavity of the microwave unit where the product was placed to provide uniform temperatures throughout and while in use.

Drying Test and Procedure

A total of 27 drying runs were conducted at three specific energy levels of 194, 258, and 322 Btu/lb, bed thickness of 0.4, 1.2, and 2.0 in., and 480 sec drying duration. The choice of the specific energy levels was adopted based on our previous work on microwave batch drying of rice where we reported that 258 Btu/lb was found to be optimum in a batch process that also incorporated tempering of rice after MW heating as an additional step. For a particular experimental run, the appropriate sample size was weighted and fed into the hopper in which the outlet was pre-set at the expected bed thickness and the corresponding power (using Eq. 1 and Table 1).

$$P = \frac{7.5ME}{t} \qquad \text{Eq. 1}$$

Where: P is the power applied (Btu/h), M is the mass (lb), E is the specific energy (Btu/lb) and t is the duration of heating (h).

As samples were conveyed out of the heating chamber to the collection point, three different subsamples weighing 4.4 lb each were collected at the beginning, middle, and toward the end of the bed. Samples collected were transferred into different glass jars immediately and the jars were sealed and placed inside an incubator (VWR, Radnor, Pa.) that was pre-set at a temperature of 104 °F for 4 h. After tempering, the samples were removed from the jars and spread on a flat wire mesh and allowed to gradually cool down until surface temperatures dropped to ambient condition inside a controlled envi-

ronment with temperature and relative humidity of 79 °F and 56%, respectively (5580A, Parameter Generation and Control, Black Mountain, N.C.) (Jindal and Siebenmorgen, 1994). The MC of the cooled sample was determined. The percentage point moisture removed before MW heating and after cooling was calculated as the difference between the original and final MCs after cooling.

Rice Dehulling and Milling

A weight of 0.33 lb was measured from each sample and was de-hulled using a laboratory Sheller (THU 35B, Satake Engineering Co., Tokyo, Japan) with a clearance of 0.02 in. between the rollers. The resultant brown rice was milled (McGill No.2. RAPSCO, Brookshire, Texas) for 30 sec. The milled rice was quantified and then the brokens were separated from the lots with a sizing device (61 Grain Machinery manufacturing Corp., Miami, Fla.) and the resulting mass of head rice was quantified. The white rice (both broken and rough remaining) was clearly marked for subsequent analysis.

Milling Yield and Head Rice Properties

The milled rice from the treatment described above was then separated into the head rice out of the milled fraction using a double-tray shaker table (Grain, Grain Machinery Corp., Miami, Fla.) with both trays having indented holes (3.96 for medium-grain). The holes are used to separate the broken kernels from the head rice. Hence, HRY was calculated as the weight percentage of rough rice that remained as head rice. All HRY determinations were replicated and reported as average values.

Statistical Analysis

All experiments were conducted in triplicate. The results are presented in relevant sections as mean values and standard deviation. Analysis of variance was conducted using a generalized linear model and surface response methodology from SAS statistical software (SAS Institute Inc., Cary, N.C.). In addition, a pairwise *t*-test using least square mean with Tukey multiple comparison test was computed for each effect and the interactions. Significant difference for interaction effects was separated by letter reporting. All tests were considered to be significant when $P \leq 0.05$.

RESULTS AND DISCUSSION

Effect of Microwave Treatment on Moisture Reduction

The moisture loss rates were 0.018, 0.033, and 0.027 g/g/sec for 0.4 in., 1.2 in., and 2.0 in. bed thickness, respectively. The moisture loss first increased then reduced as bed thickness increased from 0.4 in. to 1.2 in. The moisture loss at 1.2 in. bed thickness was highest with about 88% and 22% higher at 0.4 in. and 2.0 in. bed thickness,

respectively. Similarly, moisture loss increased from 6% to 15% as specific energy increased from 194 to 322 Btu/lb. However, moisture loss at 258 and 322 Btu/lb were not significantly different. The surface response plot of the effect of thickness and specific energy on moisture loss is shown in Fig. 2.

Effect of Microwave Treatment on HRY Reduction

The HRY of controlled samples dried at 79 °F, 56% relative humidity was found to be 67.0%. Although, the HRY of the sample treated at 0.4 in. bed thickness with specific energy of 194 Btu/lb was almost the same as the control, the difference was not statistically significant. Generally, HRY reduced from 66% to 37% as specific energy increased from 194 to 322 Btu/lb. From the response surface plot (Fig. 3), it can be seen that the linear relationship occurred between HRY and specific energy applied; this was in agreement with the findings of Wadsworth (1993). An increase in specific energy increased the intensity of MW power and increased the rate of moisture removal and thermal stress in the kernel. This resulted in rice fissuring and reduction in HRY.

Effect of Microwave Treatment on Milling Yield

Increasing bed thickness and specific energy resulted in a reduction in milling yield from 73% to 62%. Milling yield reduced because of the brittleness of kernel as a result of moisture removal and thermal stress. Both MRY and HRY are highly dependent upon the physical condition of rough rice kernels after drying. The effect of specific energy and bed thickness were significant on the milling rice yield ($R^2 = 0.95$, RMSE = 2.5, Table 2).

SIGNIFICANCE OF FINDINGS

The findings from this study show that freshly harvested rough rice can be dried using microwave with minimal reduction in HRY and MRY. It was observed that treatment at 194 Btu/lb with bed thickness of 0.4 in. resulted in dried rice with optimum MRY and HRY.

ACKNOWLEDGMENTS

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Table 1. Experimental design.

Specific energy	Bed thickness	Total mass	Power
[Btu/lb (kJ/kg)]	[In. (m × 10^{-3})]	[lb (kg)]	[Btu/h (kW)]
194 (450)	0.4 (1)	211.6 (96.08)	10236.426 (3)
	1.2 (3)	635.5 (288.26)	30709.278 (9)
	2.0 (5)	1059.1 (480.43)	51182.13 (15)
258 (600)	0.4 (1)	211.6 (96.08)	13648.568 (4)
	1.2 (3)	635.5 (288.26)	40945.704 (12)
	2.0 (5)	1059.1 (480.43)	68242.84 (20)
322 (750)	0.4 (1)	211.6 (96.08)	17060.71 (5)
	1.2 (3)	635.5 (288.26)	51182.13 (15)
	2.0 (5)	1059.1 (480.43)	85303.55 (25)

Table 2. Statistical analysis of the effect of microwave treatments on the milled rice yield of rough rice.

Factors	DF	Type I SS	Mean square error	F Value	Pr °> °F
Specific energy (Btu/lb)	2	146.91	73.45	11.32	0.0012
Thickness (inches)	2	1827.63	913.81	140.88	<0.0001
Power (Btu/h)	2	110.17	55.08	8.49	0.0038

Fig. 1. Industrial-type microwave system used in the study showing the transmitter (1), wave guide (2), heating zone (3), conveyor belt (4), and control panel (5).

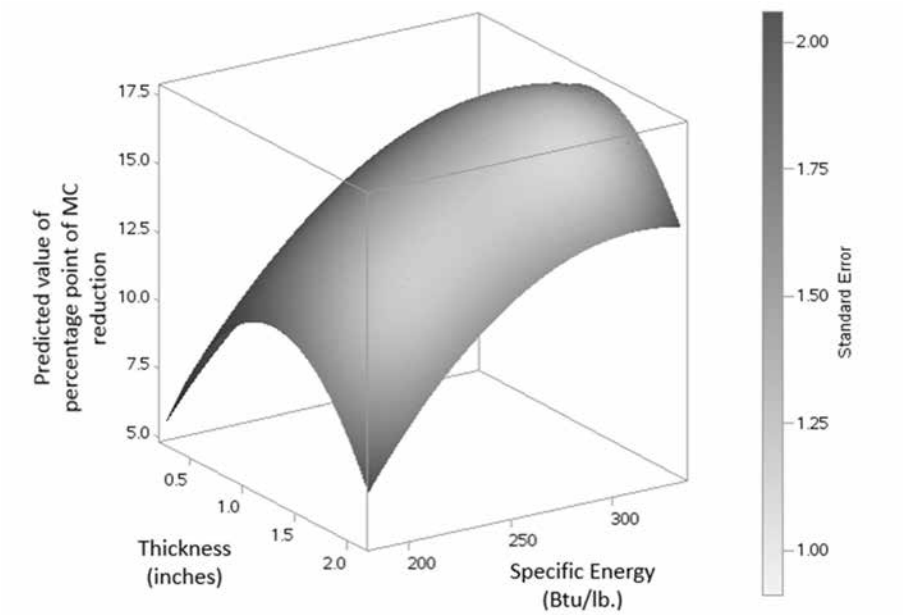

Fig. 2. Surface response of the effect of microwave treatments on percentage point moisture content (MC) reduction of rough rice with initial moisture content at 24% to 25% wet basis.

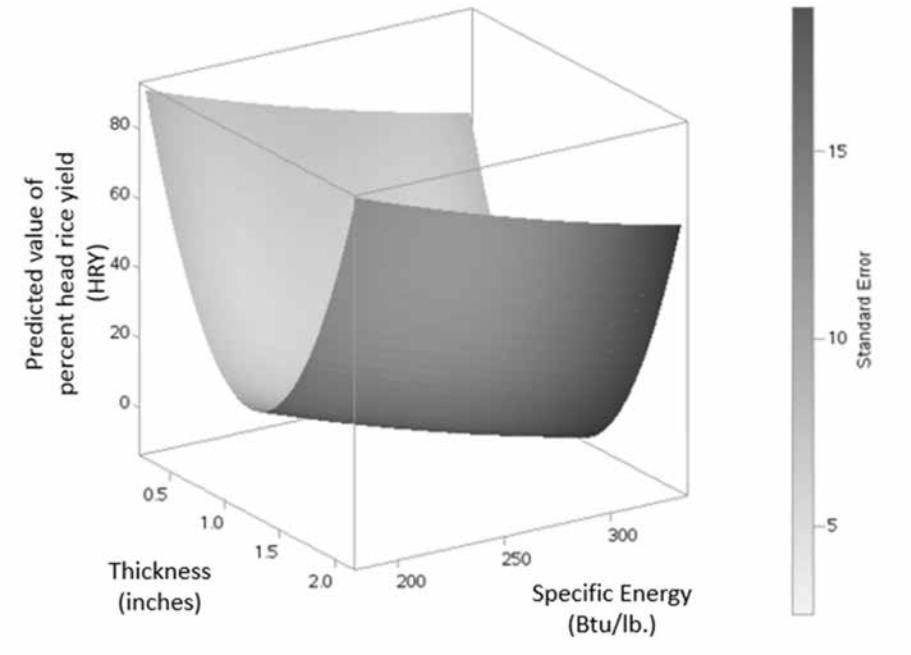

Fig. 3. Surface response for head rice yield (HRY) at different thickness and specific energy.

Impacts of Rough Rice Temperature and Moisture Content on Laboratory Milling Yields

B.C. Grigg[1], C.D. Shook[1], and T.J. Siebenmorgen[1]

ABSTRACT

Milling yields of a rice lot are often estimated using a laboratory-scale mill and a set milling duration. Temperature and moisture content of the rice sample can affect the milling results from such mills. A study was conducted to illustrate the impacts and potential interactions of rough rice temperature (40 °F, 55 °F, 70 °F, and 85 °F) and moisture content (MC; 10%, 12%, and 14% MC; wet basis, w.b.) at the time of milling; measurements comprised milled rice yield (MRY), head rice yield (HRY), and surface lipid content (SLC, representing the degree of milling), for lots of the long-grain XL753 and the medium-grain Jupiter rice. All samples were milled using a McGill No. 2 mill for 30 s. For the XL753 lot, increasing rough rice temperature and/or MC resulted in decreased MRYs, HRYs, and SLCs. For the Jupiter lot, increasing rough rice temperature and/or MC decreased SLCs; however, only increasing rough rice MC levels resulted in significantly decreased MRYs and HRYs. No significant interactions between rough rice temperature and MC were observed with respect to MRYs or HRYs of either rice lot. Compared to rough rice temperature, rough rice MC had a greater impact on milling yields within each rice lot. These data support reporting of milling yields at a consistent SLC to equitably valuate rice lots of different temperatures, MCs, and cultivars.

INTRODUCTION

The economic value of rough rice (*Oryza sativa* L.) is largely determined by milled rice yield (MRY)—the mass fraction of unprocessed, rough rice that remains as milled rice, including both head rice and broken kernels—and head rice yield (HRY)—the mass fraction of rough rice that remains as head rice, defined as well-milled rice kernels three-fourths or more of the original kernel length (USDA-FGIS, 2009). Well-milled rice refers to the degree of milling (DOM), the extent of bran removal from brown rice during milling. Increased DOM invariably increases the mass removed from rice kernels, thus decreasing MRY (Wadsworth, 1994) and HRY (Lanning and Siebenmorgen, 2011).

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Surface lipid content (SLC, the amount of oil/lipid remaining on milled kernels) is often used to represent DOM (decreasing SLC corresponds to increasing DOM), both in laboratory operations (Cooper and Siebenmorgen, 2007) and commercial milling systems.

Many receivers of rough rice estimate milling yields of a rice lot using a laboratory-scale mill and a set milling duration (e.g. 30 s), regardless of the rice lot being evaluated. However, factors such as cultivar (Siebenmorgen et al., 2006), temperature (Archer and Siebenmorgen, 1995), and moisture content (MC) (Reid et al., 1998) of rough rice at the time of milling can affect the milling duration required to achieve a desired SLC. Decreasing SLC (i.e. increasing DOM) results in decreased HRY of long-grain rice cultivars (Cooper and Siebenmorgen, 2007; Lanning and Siebenmorgen, 2011). Inconsistent SLCs resulting from either over- or under-milling rice when milling for a set duration, can in turn impact milling yields (Cooper and Siebenmorgen, 2007). While studied independently, the potential interactions between rough rice temperature and MC have not been reported. Thus, a study was conducted to illustrate the impacts and potential interactions of rough rice temperature and MC at the time of milling on milling yields and SLC.

PROCEDURES

One long-grain (XL753) lot and one medium-grain (Jupiter) lot were evaluated. Both lots were cleaned with a dockage tester (XT4, Carter-Day, Minneapolis, Minn.), and conditioned in a climate-controlled chamber (5580A, Parameter Generation & Control, Black Mountain, N.C.) to one of three moisture contents (MCs), 10%, 12%, or 14% (all ± 0.5% MC, wet basis). A moisture meter (AM5200, Perten Instruments, Hägersten, Sweden) was used to measure MC. For each MC, sixteen 150-g samples of rough rice from each lot were placed in zippered plastic bags, with four bags stored at each of four temperatures (40 °F, 55 °F, 70 °F, or 85 °F) for 24 h. As such, the study comprised 96 samples (2 cultivars × 3 MCs × 4 temperatures × 4 replications).

Samples of rough rice were individually removed from their controlled-temperature environments immediately before dehulling and milling. Each sample was first dehulled using a laboratory sheller (THU 35B, Satake Corp., Hiroshima, Japan) with a clearance of 0.019 in. between the rollers. Then each sample was milled for a 30-s duration in a laboratory-scale mill (McGill No. 2, RAPSCO, Brookshire, Texas), equipped with a 3.3-lb weight on the lever arm, situated 6 in. from the milling chamber centerline. Both MRY and HRY were determined, with head rice being separated from broken kernels using a sizing device (61, Grain Machinery Manufacturing Corp., Miami, Fla.). Head rice DOM was quantified in terms of surface lipid content (SLC) using a near-infrared-reflectance (NIR) spectrophotometer (DA7200, Perten Instruments, Hägersten, Sweden) (Saleh et al., 2008).

Analysis of variance ($P = 0.05$), and means separation (Tukey-Kramer Honestly Significant Difference), were conducted using statistical software (JMP v. 12.0, SAS Institute, Inc., Cary, N.C.).

RESULTS AND DISCUSSION

Increasing the rough rice temperature of the long-grain, XL753 lot from 40 °F to 85°F decreased MRYs by 0.5 percentage points (pp) (Fig. 1a), and HRYs by 1.6 pp (Fig. 1c). Increasing the rough rice MC of the long-grain lot from 10% to 14% decreased MRYs by 2.2 pp (Fig. 1b), and HRYs by 6.3 pp (Fig. 1d). Similar to the trends described for milling yields (Fig. 1a-d), SLCs of the long-grain lot decreased by 0.06 pp in response to increasing rough rice temperature (Fig. 1e), and by 0.14 pp in response to increasing rough rice MC (Fig. 1f). Thus, for the ranges of rough rice temperature and MC levels evaluated, rough rice MC at the time of milling had a greater impact on the magnitudes of MRYs, HRYs, and SLCs of the long-grain lot (Fig. 1a-f).

For the medium-grain, Jupiter lot, increasing rough rice temperature resulted in significantly decreased SLCs (Fig. 2e). Increasing the rough rice temperature of the medium-grain lot produced a slight trend of decreasing MRYs and HRYs (Fig. 2a and c); however, there were no statistical differences in either MRYs or HRYs. As observed for the long-grain lot (Fig. 1), increasing rough rice MCs resulted in significant, corresponding decreases in MRYs, HRYs, and SLCs of the medium-grain lot (Fig. 2b, 2d, and 2f). Thus for the medium-grain lot, rough rice MC again had a greater impact on the magnitudes of MRYs when compared to rough rice temperature. Differences in the responses of the two lots to changing rough rice temperature/MC levels illustrate the effects of cultivar/type on milling characteristics, as previously shown between long-grain cultivars (Siebenmorgen et al., 2006; Lanning and Siebenmorgen, 2011), and between long-grain and medium-grain types (Pereira et al., 2008).

Only a single statistically significant interaction between rough rice temperature and MC was observed; this for SLCs of the long-grain lot, decreasing greatly when increasing rough rice temperature from 70 °F to 85 °F at the 10% MC level (Fig. 3a). While not statistically significant, a similar trend for decreased SLC was observed with the same temperature/MC combinations for the medium-grain lot (Fig. 3b). However, for the rough rice temperatures and MCs evaluated, there were no significant interactions with respect to MRYs of either rice lot.

SIGNIFICANCE OF FINDINGS

At a set 30-s milling duration, increasing rough rice temperature and/or MC decreased SLCs (i.e. increased DOM) of both long-grain and medium-grain lots, with rough rice MC levels having a greater impact than rough rice temperature. While the trends of MRY, HRY, and SLC were similar for the two lots, the rice cultivar/type affected the overall magnitude of the response. Increasing either rough rice temperature or MC decreased MRYs of the long-grain lot, agreeing with previous reports for long-grain rice (Archer and Siebenmorgen, 1995; Reid et al., 1998). Similar to the long-grain lot, increased rough rice temperature and/or MC resulted in trends for decreased MRYs of the medium-grain lot; however, only increasing rough rice MC levels resulted in statistically significant differences. These data illustrate cultivar-dependent milling characteristics, agreeing with the report of Siebenmorgen et al. (2006), which recommended milling

to a consistent DOM for equitable comparison of HRYs across cultivar lots. Moreover, these data suggest the need for milling to consistent DOM levels in response to different levels of rough rice temperature and MC, within and across rice lots. The SLC values of head rice samples can be rapidly measured using NIR instruments (Saleh et al., 2008), allowing for subsequent mathematical adjustment of HRYs to an equitable DOM level (Pereira et al., 2008). This readily accounts for different sample SLCs that may result from variations in MC, temperature, or cultivar of rough rice samples.

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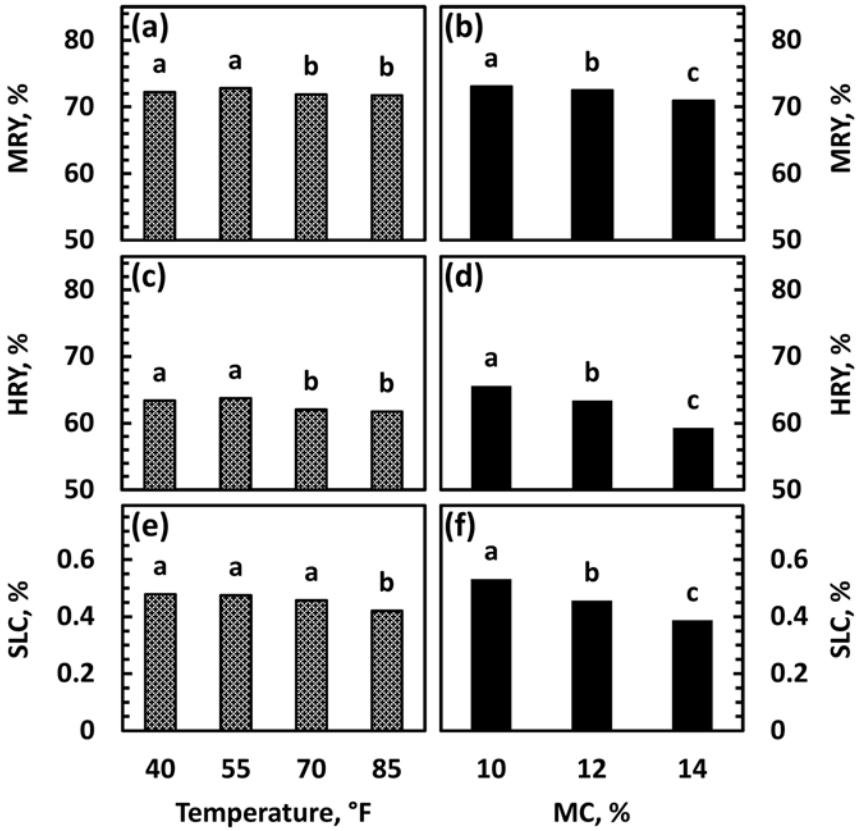

Fig. 1. Impacts of rough rice temperature or moisture content (MC) at the time of milling on milled rice yield (MRY) (a-b), head rice yield (HRY) (cd)], and surface lipid content (SLC) of head rice (e-f) of the long-grain (XL753) rice lot. Samples were milled with a McGill No. 2 mill for 30 s. When considering temperature impacts, data are averaged across MCs. When considering MC impacts, data are averaged across temperatures. Means with the same letter were not statistically different; comparisons are valid only within a subgraph.

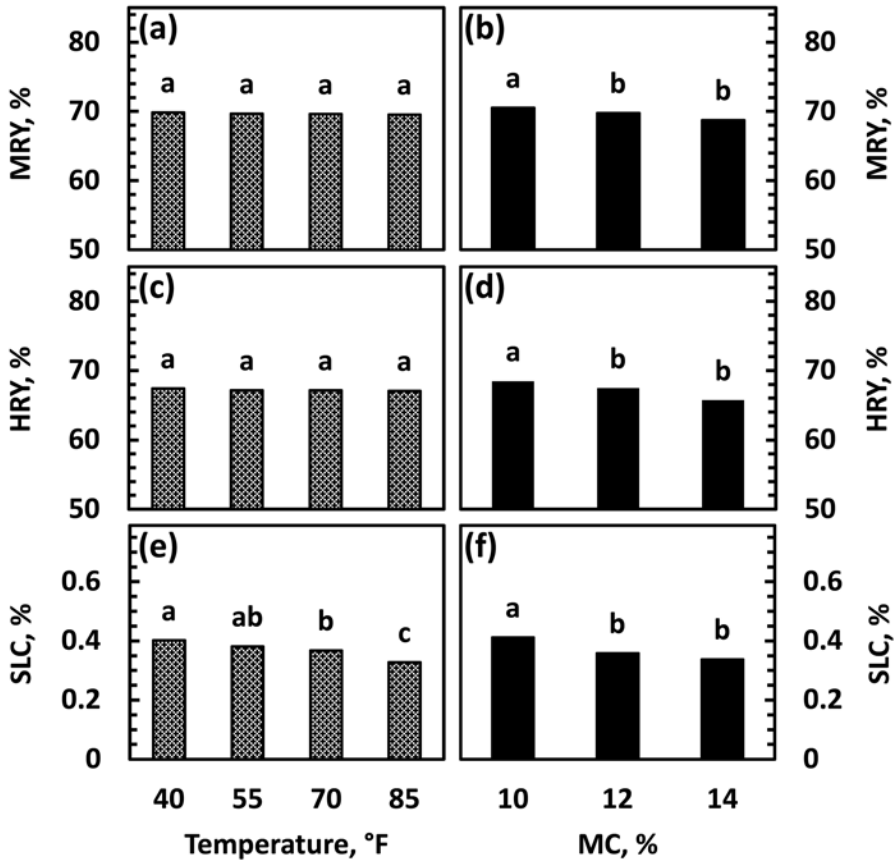

Fig. 2. Impacts of rough rice temperature or moisture content (MC) at the time of milling on milled rice yield (MRY) (a-b), head rice yield (HRY) (cd), and surface lipid content (SLC) of head rice (e-f) of the medium-grain (Jupiter) rice lot. Samples were milled with a McGill No. 2 mill for 30 s. When considering temperature impacts, data are averaged across MCs. When considering MC impacts, data are averaged across temperatures. Means with the same letter were not statistically different; comparisons are valid only within a subgraph.

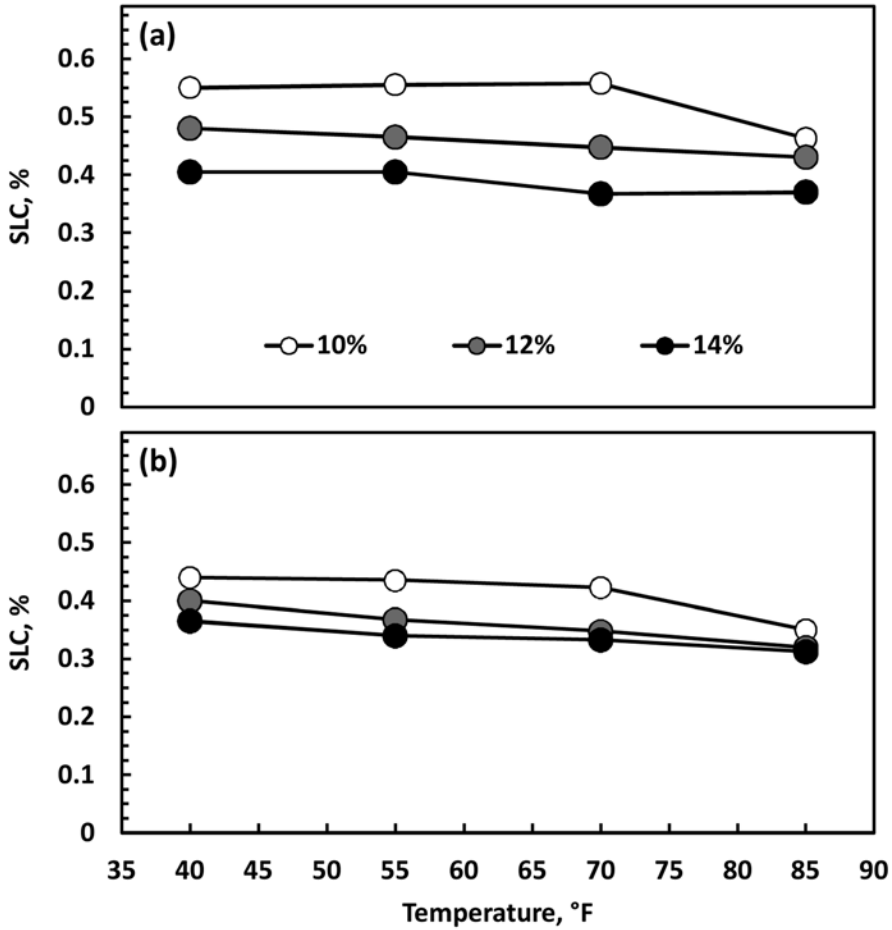

Fig. 3. Surface lipid content (SLC) of head rice of (a) long-grain (XL753) and (b) medium-grain (Jupiter) rice lots as impacted by rough rice temperature and moisture content (MC) at the time of milling. Samples were milled with a McGill No. 2 mill for 30 s.

Effects of Temperature, Moisture Content, and Rough Rice Storage Duration on Milling Properties and Discoloration

K.N. Haydon[1] and T.J. Siebenmorgen[1]

ABSTRACT

Two long-grain rice cultivars, XL753 and CL XL745, both grown in Arkansas in 2014, were stored in rough rice form at moisture contents (MCs) of 12.5%, 16%, 19%, and 21% (wet basis) at temperatures of 50 °F (10 °C), 59 °F (15 °C), 68 °F (20 °C), 81 °F (27 °C), and 104 °F (40 °C) for a total of 16 weeks, with samples taken at 2, 4, 6, 8, 10, 12, and 16 weeks. After drying, dehulling, and milling to an approximate surface lipid content (SLC) of 0.4%, head rice was separated from broken kernels and discoloration of the head rice was measured by a pixel-by-pixel assessment of kernel area with color values established by a set of discolored kernels of interest chosen from this study. Head rice yield declined only when discoloration had already developed on milled rice. Two divergent patterns of discoloration appeared in 21%-MC rice stored at 81 °F (27 °C) and 104 °F (40 °C) for at least 8 weeks. The head rice from samples stored at 50 °F (10 °C) and 59 °F (15 °C) at MCs up to 21% and 19%, respectively, did not show any significant color degradation throughout the storage duration, indicating that grain chilling may be a viable option for maintaining quality in undried rough rice.

INTRODUCTION

At high moisture contents (MCs), rough rice respires rapidly, especially in the hot temperatures typical of Arkansas in August and September, promoting fungal growth with the potential for mycotoxin development, and discoloration. Respiration contributes to many deleterious effects on rice quality, including dry matter loss and kernel discoloration (Smith and Dilday, 2003).With a fixed storage temperature of 77 °F (25 °C), Trigo-Stockli and Pederson (1994) found that increasing rough rice MC leads to increased kernel discoloration, reduced milling yields, and reduced seed germination rates over 30 days; fungal growth also generally increased with increasing MC. Drying within a short period of time after harvest is therefore recommended for maintaining rice quality.

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Theoretically, however, the quality of high-MC rough rice could be maintained by short-term storage with a grain cooling system. According to Brunner (1986), cooling was used in the 1960s to preserve fresh rice in the interim between harvest and drying, yet this is not widely practiced now. Utilizing cooling systems could enable farmers to safely hold rice before accessing commercial dryers or before parboiling. Industry research suggests multiple benefits of grain cooling, including cool-temperature retention without additional cooling for several months, reduction of dry-matter loss, prevention of insect infestation, mold growth, and discoloration, a small reduction in grain MC thereby reducing drying costs, and preservation of head rice yield (HRY; Kolb, 2008; Kolb and Braunbeck, 2013).

This study was designed to both evaluate the viability of grain cooling systems and to determine the inter-related impacts of MC, temperature, and storage duration on milling properties and discoloration of rice. This research also developed a novel system of quantifying discoloration that uses computer software, rather than human judgment, to gauge whether rice is discolored or not.

PROCEDURES

Two long-grain hybrid rice cultivars, XL753 and CL XL745, grown at the University of Arkansas System Division of Agriculture's Northeast Research and Extension Center (NEREC) in Keiser, Ark., and Running Lakes Farm near Pocahontas, Ark., respectively, were harvested in 2014 at approximately 22% MC (wet basis). The rice was cleaned with a dockage tester (Model XT4, Carter-Day, Minneapolis, Minn.) and conditioned to MCs of 21%, 19%, 16%, and 12.5% as measured by a moisture tester (AM 5200, Perten Instruments, Hägersten, Sweden). Rice was placed in quart glass Mason jars and distributed among temperature-controlled storage units maintained at 50 °F (10 °C), 59 °F (15 °C), 68 °F (20 °C), 81 °F (27 °C), and 104 °F (40 °C). One jar of each cultivar/MC/temperature combination was removed after each of seven storage durations: 2, 4, 6, 8, 10, 12, and 16 weeks. The storage conditions are summarized in Table 1. After storage, the rough rice was dried to 12.5% MC.

Duplicate 5.20 oz (150 g) rough rice samples from each jar were dehulled with an impeller husker (Model FC2K, Yamamoto, Yamagata, Japan), then milled using a laboratory mill (McGill No. 2, RAPSCO, Brookshire, Texas), having a 3 lb 5 oz (1.5 kg) mass placed on the lever arm, 15 cm from the centerline of the milling compartment. Milling durations were 17 s and 22 s for XL753 and CL XL745, respectively, which resulted in a head rice surface lipid content (SLC) of 0.4%. After milling, head rice was separated from brokens using a sizing device (Model 61, Grain Machinery Manufacturing Corp., Miami, Fla.), and head rice SLC was verified by a diode array near-infrared reflectance (NIR) analyzer (DA 7200, Perten instruments, SE-141 05 Huddinge, Sweden).

Head rice color was measured with an image analysis system (WinSEEDLE Pro 2005aTM, Regent Instruments Inc., Sainte-Foy, Quebec, Canada). Approximately 100 kernels were arranged on a clear, acrylic tray, placed on a flatbed scanner, and imaged

with a blue background. The software analyzed the area of the kernels and quantified what percent of the kernel area was occupied by pixels of pre-set color values. These values were established by a set of discolored kernels chosen from samples in this study. Eight different colors were measured: white, three shades of yellow, red/brown, brown/black, pink/red, and salmon/light pink. Two trays of kernels were analyzed from one of the two sub-millings from each jar of rice. The total discoloration of the kernels was calculated as the sum of all of the non-white color percentages.

Head rice yield from two sub-millings from each jar of rice and total discoloration from two trays analyzed from a single sub-milling from each jar were averaged and plotted against storage duration for each temperature and moisture content, and the statistical significance of these correlations were determined by analysis of variance (ANOVA) at $P = 0.05$ using linear regression analysis (JMP Pro v. 12.0.1, SAS Institute, Inc., Cary, N.C.).

RESULTS AND DISCUSSION

At storage temperatures of 50 °F (10 °C) and 59 °F (15 °C), HRY was maintained in CL XL745 stored at MCs up to 21% at 50 °F or 19% at 59 °F for the entirety of the 16 week storage period (Fig. 1, Table 2). The data from XL753 is not shown, but this cultivar exhibited very similar trends to CL XL745. Though the HRY reductions in 12.5%-MC rice stored at or above 68 °F were slight, they were statistically significant. Head rice yield losses of a larger magnitude only occurred in rice stored at 21% MC, and primarily at temperatures of 81 °F (27 °C) and 104 °F (40 °C) after 8 weeks, though HRY also significantly decreased after 16 weeks of storage in rice stored at 59 °F (15 °C). There was typically visible mold present on these samples that may have impacted the physical integrity of the kernels, leading to greater breakage during milling. These reductions in HRY only occurred after discoloration had already exceeded acceptable levels (Fig. 2). A rough rice storage study conducted by Houston et al. (1957) also found that HRY losses only occurred after other extensive quality reductions.

Because XL753 and CL XL745 were very similar with respect to total discoloration over the storage duration, the data from both cultivars were pooled (Fig. 2, Table 2). Storage at 50 °F (10 °C) maintained a low level of discoloration in rice of all MCs for the entire 16-week storage duration. At 21% MC, a small increase in discoloration occurred after 10 weeks of storage at 59 °F (15 °C) and 68 °F (20 °C). Storage at 81 °F (27 °C) caused a significant increase in discoloration over 16 weeks in rice stored at 19% and 21%. Discoloration increased significantly over time in rice at all four MCs stored at 104 °F (40 °C), with the magnitude of changes in discoloration also increasing with increasing MC.

Two patterns of discoloration appeared at 81 °F (27 °C) and 104 °F (40 °C) in rice stored at 21% MC for at least 8 weeks (Fig. 3, presented for illustrative purposes only). Data from 16 weeks were excluded due to extreme kernel integrity degradation that skewed individual color measurements. Though yellow was the predominant color at both temperatures (Fig. 3d), at 104 °F the milled rice appeared uniformly yellow

with other colors only appearing at barely noticeable levels. At 81 °F, a mottled pattern appeared, with a combination of white, yellow (Fig. 3d), pink/red (Fig. 3a), black/brown (Fig. 3b), and red/brown (Fig. 3c) kernels. Yellowing at 104 °F (40 °C) occurred in rice of all MCs, even 12.5% MC (Fig. 3d). The mechanism for the divergent color patterns is unknown, but these results corroborate findings from discolored rice samples obtained from on-farm bins.

Though some researchers favor fungi as the true causes of discoloration due to their coincident appearance, Belefant-Miller et al. (2005) argue this is not the case. This study observed that discoloration penetrates the endosperm, but fungal hyphae were not found within the endosperm of yellowed samples. Also, yellowing was induced in fungus-free endosperm from rice plants grown from fungicide-treated seed and sprayed with fungicide during development. However, Belefant-Miller et al. used 5-day incubations at the longest and temperatures of 142.7 °F to 178.9 °F (61.5 °C to 81.6 °C), so fungi cannot be ruled out in the present study given the possibility that discoloration occurs by a different mechanism at temperatures of 68 °F (20 °C) to 104 °F (40 °C) maintained throughout 16 weeks of storage. Until the mechanism for post-harvest kernel discoloration is found and understood, interventions such as cooling may be used to mitigate these discoloration effects.

SIGNIFICANCE OF FINDINGS

For current storage or in-bin drying systems that do not utilize cooling, these results demonstrate the importance of thorough drying, as well as proper temperature control through aeration. Even fully dried rice was susceptible to discoloration after only 6 weeks at 104 °F (40 °C). Because the top layer of a drying bin requires the longest duration to dry, it may therefore maintain a MC at or above 21% for several weeks. Hot, early-autumn temperatures typical of Arkansas rice harvest season may induce discoloration in this high-MC layer.

With respect to color and HRY, cooling to temperatures of 50 °F (10 °C) may offer a viable solution for short-term storage of rice at MCs up to 21%. Though milling properties did not change over the 16-week storage period at cool temperatures, it is not known how these conditions, which also slow aging effects on starch structure (Swamy et al., 1978), would affect processing characteristics in operations such as parboiling. This study is being repeated with rice grown and harvested in 2015 to confirm the findings from 2014. Further study is needed to understand the causes of discoloration, especially as they relate to the temperature-dependent patterns observed in this study.

ACKNOWLEDGMENTS

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Table 1. Overview of the experimental design.

Cultivars	Initial moisture content	Temperature	Duration
	(%)	[°F (°C)]	(weeks)
XL753	12.5	50 (10)	2
CL XL745	16	59 (15)	4
	19	68 (20)	6
	21	81 (27)	8
		104 (40)	10
			12
			16

Table 2. Correlation coefficients of total discolored kernel area (%) with storage duration for cultivars XL753 and CLXL745 (data pooled and averaged), and of head rice yield (%) with storage duration for cultivar CLXL745.

		Moisture content			
	Temperature	12.5%	16.0%	19.0%	21.0%
	[°F (°C)]	----------(%)----------			
Head rice yield (%)	50 (10)	NS[a]	NS	NS	NS
	59 (15)	NS	NS	NS	-0.67
	68 (20)	-0.7	-0.5	NS	NS
	81 (27)	-0.65	NS	NS	-0.7
	104 (40)	-0.71	NS	NS	-0.66
Discolored kernel area (%)	50 (10)	NS	NS	NS	NS
	59 (15)	NS	NS	NS	0.68
	68 (20)	NS	NS	NS	0.69
	81 (27)	NS	NS	0.52	0.7
	104 (40)	0.72	0.87	0.95	0.91

[a] NS = not significant.

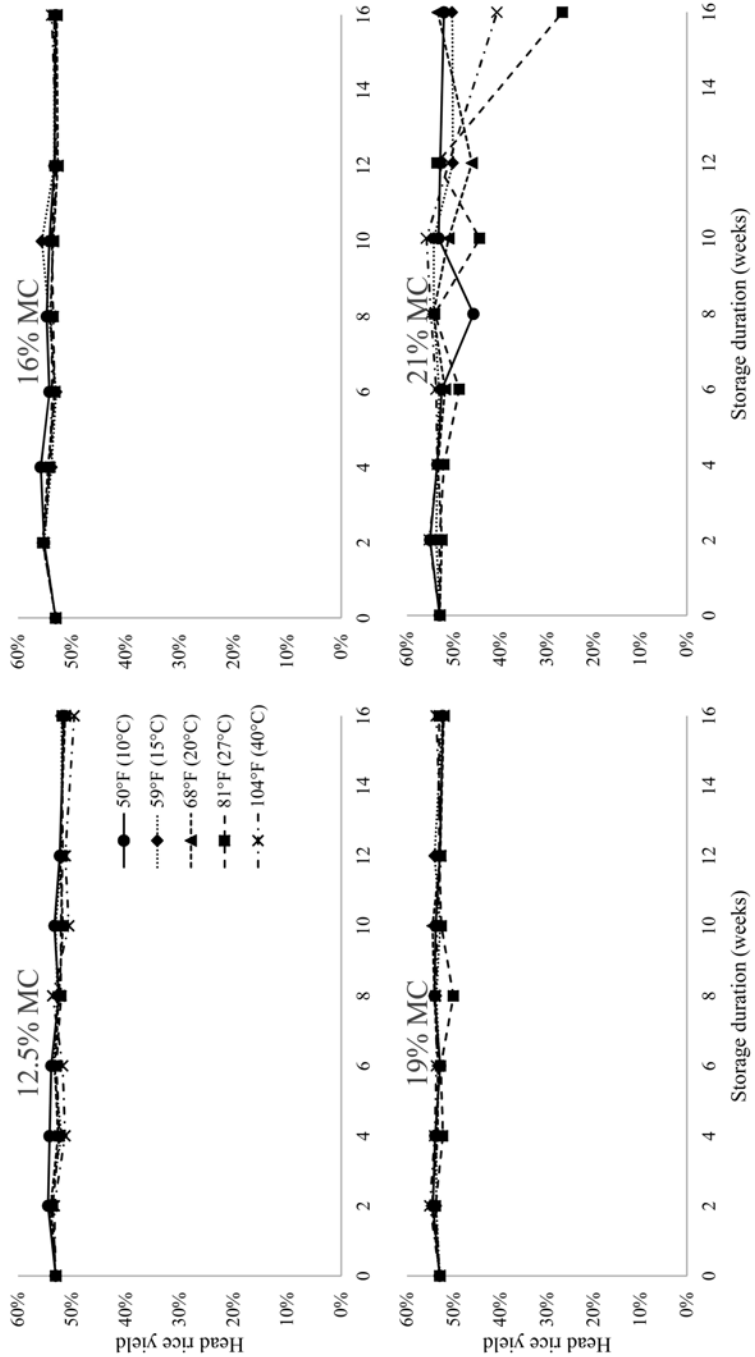

Fig. 1. Head rice yield (HRY) of CL XL745 over 16 weeks of storage as affected by rough rice moisture content (MC) and storage temperature. These figures include a baseline, pre-storage HRY at 0 weeks that is the same for all MCs and temperatures, representing rice that was dried immediately after harvest, then milled.

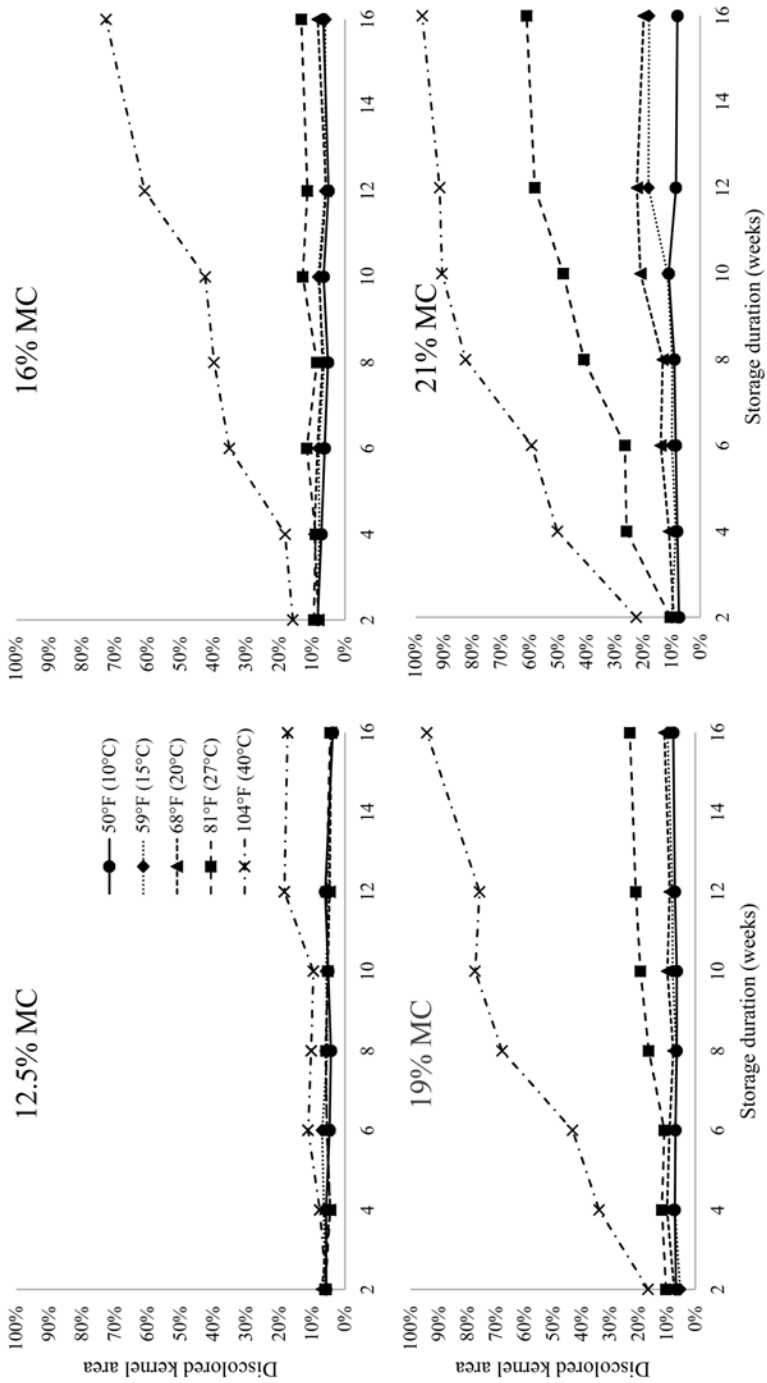

Fig. 2. Total percentage of kernel area that was discolored (any non-white color) of XL753 and CLXL745 over 16 weeks of storage as affected by rough rice moisture content (MC) and storage temperature.

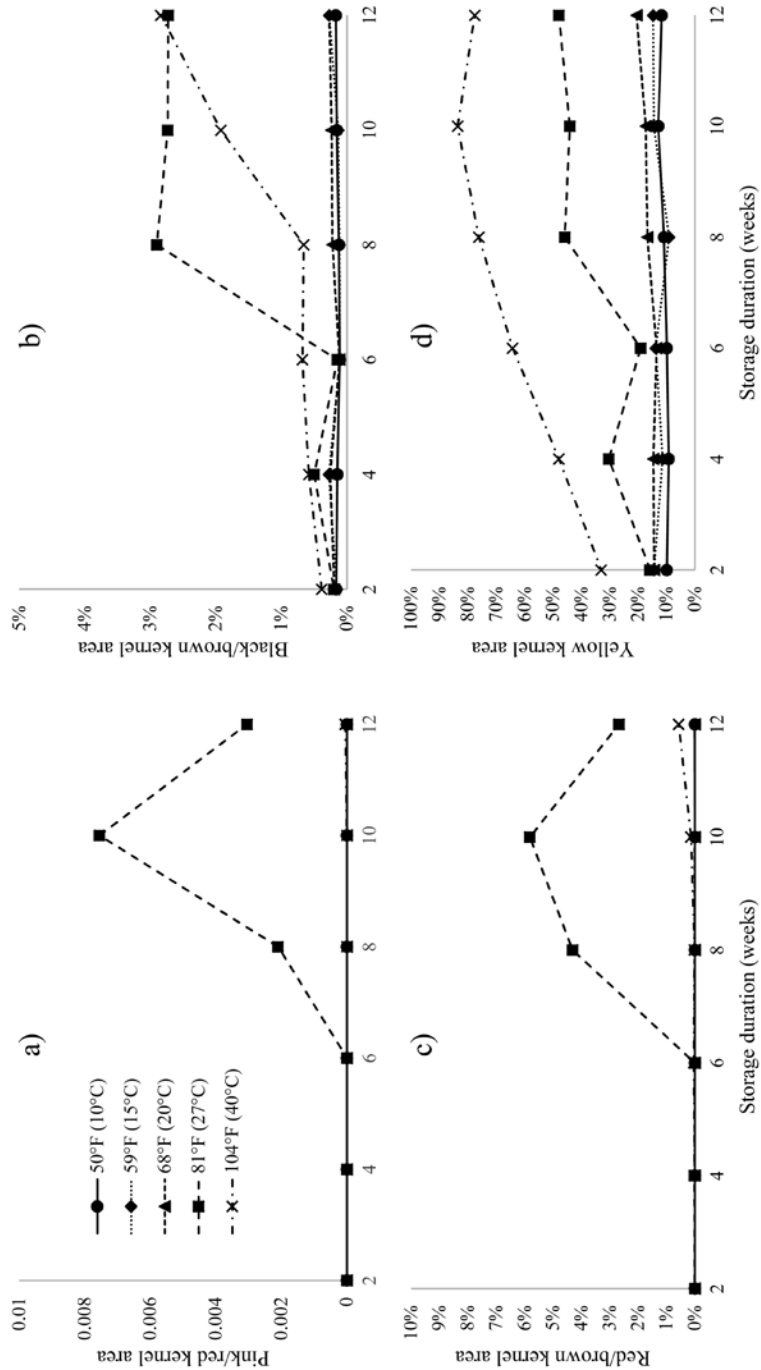

Fig. 3. Percentage of kernel area occupied by a) pink/red, b) black/brown, c) red/brown, and d) yellow of 21% moisture content XL753 over 12 weeks of storage as affected by storage temperature. Y-axes only extend to 1% for pink/red, 5% for black/brown, and 10% for red/brown to allow for trendline visibility.

Variable Impact of Nighttime Air Temperatures on Rice Chalk and Milling Properties Due to Heading Date

K.N. Haydon[1], T.J. Siebenmorgen[1], and P.A. Counce[2]

ABSTRACT

High nighttime air temperatures (NTATs) during reproductive growth stages (R-stages) are known to cause increased chalkiness and reduced head rice yields (HRYs) in susceptible rice cultivars. These effects have been clearly demonstrated in field trials conducted from 2007-2010 across the eastern Arkansas rice-growing region (Ambardekar et al., 2011; Lanning et al., 2011). Field trials continued from 2011-2014 in order to further verify these NTAT impacts on an expanded set of cultivars. Analysis of the 2012 and 2014 growing years indeed confirmed the trends of increasing chalk and decreasing HRY with increasing NTATs during critical R-stages. However, in 2011 and 2013 the trends were quite different among many cultivars. This was attributed to the abnormal growing environment in these years, when spring rains forced late planting, leading to significantly later heading dates and markedly reduced NTATs during later R-stages. These results demonstrate that during years of late planting with late heading of rice, NTAT is not an entirely accurate predictor of rice quality, as temperatures below a certain threshold may counterintuitively reduce quality.

INTRODUCTION

The reproductive growth stages (R-stages) of rice are highly sensitive and critical times for plant development, especially the grain-filling stages (R6 to R8). Ambardekar et al. (2011) and Lanning et al. (2011) documented correlations between high nighttime air temperatures (NTATs) during grain-filling, reduced milling quality, and elevated rice chalkiness during the 2007-2009 and 2007-2010 harvest years, respectively. However, because rice is a warm-season crop, it is highly susceptible to the effects of cold stress. In Arkansas, late planting can be prompted by wet spring weather, postponing drill-seeding until fields are acceptably dried. Consequently, rice may begin maturing as summer temperatures cool and day lengths shorten.

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Resurreccion et al. (1977) showed that plants exposed to either day or night temperatures below 68 °F (20 °C) or above 86 °F (30 °C) from 3 days before flowering through full maturity both produced a greater proportion of chalky kernels. The effects of cold-temperature exposure are being considered here due to the phenomenon of late 50% heading dates, a condition prompted by late planting dates that increase the likelihood of cooler temperatures during critical maturation stages (Siebenmorgen et al., 2013).

PROCEDURES

Samples were obtained from plots cultivated at multiple locations across Arkansas, spanning from northern to southern latitudes, as part of the Arkansas Rice Performance Trials. Table 1 summarizes the cultivars and locations. At every location, cultivars were assigned in a randomized block design to sub-plots within larger plots, such that each cultivar was replicated three (2011) or four times (2012-2014). Plots were harvested at moisture contents (MCs) expected to give close-to-optimum head rice yields (HRYs): approximately 19% to 22% for long-grain cultivars and 22% to 24% for medium-grain cultivars. Roughly 120 panicles from each plot were randomly selected and cut by hand, then mechanically threshed in a portable thresher (SBT, Almaco, Nevada, Iowa). All lots were cleaned using a dockage tester (Model XT4, Carter-Day Co., Minneapolis, Minn.) and conditioned to 12 ± 0.5% (wet basis) moisture content.

One 5.20 oz (150 g) rough rice sample from each lot was dehulled in a laboratory sheller (THU 35B, Satake, Hiroshima, Japan), then milled using a laboratory mill (McGill No. 2, RAPSCO, Brookshire, Texas), having a 3 lb 5 oz. (1.5 kg) mass placed on the lever arm, 5.90625 in. (15 cm) from the centerline of the milling compartment. Head rice was then separated from brokens using a sizing device (Model 61, Grain Machinery Manufacturing Corp., Miami, Fla.). Surface lipid content (SLC) of head rice was measured using a lipid extraction system in 2011 (Soxtec Avanti 2055, Foss North America, Eden Prairie, Minn.) and with a diode array near-infrared reflectance (NIR) analyzer (DA 7200, Perten instruments, SE-141 05 Huddinge, Sweden), calibrated to match extraction values, in 2012 to 2014. Head rice yield was adjusted to an arbitrary 0.4% SLC according to the finding by Pereira et al. (2008) that for every 0.10 percentage point (pp) difference in SLC from 0.4%, HRY changes in long-grain cultivars by 1.13 pp and in medium-grain cultivars by 0.85 pp.

Chalk measurements were performed on brown rice for each lot. In 2011 and 2012 this was done with an image analysis system (WinSEEDLE Pro 2005aTM, Regent Instruments Inc., Sainte-Foy, Quebec, Canada), configured to color-classify chalk by a completely chalky brown rice kernel scanned as a reference. Chalkiness was expressed as a percentage of the total kernel area. In 2013 and 2014, chalk was quantified by a similar image analysis system (SeedCount SC5000TR, Next Instruments Pty Ltd., Condell Park, NSW, Australia). The software's calibration was adjusted to correlate closely with values obtained from the WinSEEDLE system (r = 0.985).

Each year at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC) near Stuttgart, Ark., growth stages of rice

development for each cultivar were visually identified and dates of each stage's initiation from R3, the "heading date," to R9 were recorded according to the staging system developed by Counce et al. (2000). Only the heading date, R3, was recorded for each plot at all other growing locations. The staging data from Stuttgart was used to estimate when each plot at all other locations would have initiated each R-stage after R3 according to the procedure described in detail by Ambardekar et al. (2011).

There was no complete data set of R-stage measurements taken at RREC in 2011, so a 4-year average of required thermal units for each cultivar, as published by Counce et al. (2015), was utilized to estimate that year's staging data. Ambient-air temperatures were logged every 30 min with two temperature sensors (HOBO Pro/Temp Data Logger, Onset Computer Co., Bourne, Mass.) at each growing location. Data from the two sensors were averaged.

The 95th percentiles of NTATs (NT95s) during each R-stage were calculated according to the protocol used by Ambardekar et al. (2011), using nighttime ambient air temperature data, considered to begin at 8:00 PM and end at 6:00 AM. Mean chalk levels and SLC-adjusted HRYs were plotted against the NT95s during each R-stage. A multivariate analysis platform was used to determine pair-wise correlation coefficients, and the statistical significance of these correlations was determined by analysis of variance (ANOVA) at $P = 0.05$ using linear regression analysis. Tukey's Honestly Significance Test was used to compare mean HRY and chalk levels among years (JMP Pro v. 12.0.1, SAS Institute, Inc., Cary, N.C.).

RESULTS AND DISCUSSION

Of special consideration during these 4 years of research were uncharacteristically late 50% heading dates in 2011 and 2013 (Fig. 1). This was especially noticeable in 2011, when the rice reached R3 around and after mid-August rather than in mid-July to early August. This was most likely caused by late planting dates. During critical grain-filling stages in these years, the rice plants generally experienced cooler temperatures than in years when rice reached 50% heading by late July to early August. It is reasoned that these conditions may alter the trend of increasing chalk and decreasing HRYs with increasing NTATs, as warmer temperatures during relatively cooler development times may confer a benefit to the rice plants.

With this in mind, the data was partitioned into early/normal heading years (2012 and 2014) and late/atypical heading years (2011 and 2013). In normal heading years, the expected trends of increasing chalk and decreasing HRY emerged among susceptible cultivars (Fig. 2, Table 2). Atypical heading years did not demonstrate any clear trends that could clearly describe the effects of increasing temperature under such conditions. However, overall temperature climate may play a direct role in the overall HRY and chalk levels.

Rice that reached 50% heading in late July to early August experienced warmer temperatures during critical R-stages, with NT95s ranging from 73 °F (23 °C) to 82 °F (28 °C) during R8. Later-heading rice was shifted into a cooler climate during grain-filling, with NT95s as low as 64 °F (18 °C) during R8, indicating 95% of temperatures

during R8 were below 64 °F, and likely capable of producing more chalky and immature kernels, as described by Resureccion et al. (1977).

These cooler temperatures may have caused the significantly reduced HRYs and increased chalk among some cultivars in 2011 and 2013 as compared to 2012 and 2014 (Fig. 3). Previous research demonstrated variable susceptibility to high NTAT effects, and likewise these results show that cultivars respond differently to relatively low NTATs. Medium-grain cultivar Caffey and long-grain cultivars Roy J, Taggart, and XL753 exhibited significantly elevated chalk levels in 2011 and 2013 as compared to 2012 and 2014 (Fig. 3a). Caffey, Taggart, and the long-grain Wells also showed significant HRY reductions in late years (Fig. 3b). LaGrue, however, which was shown in 2007-2010 to be extremely susceptible to NTAT-induced quality reductions, was significantly chalkier in early heading years, and HRY was not significantly affected by late heading. This cultivar's tendency towards high chalk levels at high temperatures may either mask any effects due to low temperature stress, or it may indicate a degree of cold tolerance not seen in other susceptible cultivars, such as XL753 and Wells.

SIGNIFICANCE OF FINDINGS

The trends of increasing chalk and decreasing HRY with increasing NTATs, as reported previously, may only be considered reliable predictors when rice is planted at recommended times, early in the year, as in 2012 and 2014. New models for understanding temperature effects on agronomic grain yields, HRY, and chalk should consider the effect of planting and heading dates on the growing environment.

Agronomic grain yields tend to decrease with late planting and subsequent late heading dates (Siebenmorgen et al., 2013). When weather forces delayed planting, it appears to be beneficial for some cultivars with respect to chalk and milling quality to experience relatively warmer NTATs during critical grain-filling stages. Though early seeding promotes greater agronomic yields, it also creates the conditions that maximize susceptibility to elevated NTAT effects. However, late planting and low temperatures during grain-filling may also contribute to quality and yield reductions.

ACKNOWLEDGMENTS

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Table 1. Cultivars and growing locations by harvest year.

	Year			
	2011	**2012**	**2013**	**2014**
Medium-grain	Bengal Jupiter	Bengal Jupiter	Caffey Jupiter	Caffey Jupiter
Long-grain	LaGrue Wells	CL151 LaGrue Roy J Taggart XL753	Roy J Taggart XL753	CL151 LaGrue Roy J Taggart Wells XL753
Location[a]	NEREC NEC RREC	NEREC Knobel PTRS RREC	PTRS SEREC RREC	NEREC Knobel PTRS SEREC RREC

[a] NEREC = Northeast Research and Extension Center near Keiser, Ark.; NEC = Newport Extension Center near Newport, Ark.; Goodman farm (2012) and Turner farm (2014) near Knobel, Ark.; PTRS = Pine Tree Research Station near Colt, Ark.; SEREC = Southeast Research and Extension Center near Rohwer, Ark.; and RREC = Rice Research and Extension Center near Stuttgart, Ark.

Table 2. Correlation coefficients of chalk and head rice yield (HRY) with the 95th percentiles of nighttime air temperature frequencies (NT95s) during the R5 to R8 reproductive stages in 2012 and 2014. The data from these two years were pooled and only cultivars planted in both 2012 and 2014 were considered.

		Cultivars						
		Medium-grain	Long-grain					
Quality	R-stage	Jupiter	CL151	LaGrue	Roy J	Taggart	Wells	XL753
Chalk	R5	NS[a]	NS	NS	NS	NS	NS	-0.42
	R6	0.36	0.60	0.42	NS	NS	-0.64	-0.54
	R7	NS	0.37	0.53	0.43	NS	NS	NS
	R8	NS	NS	0.77	0.46	0.50	NS	NS
HRY	R5	NS	NS	NS	NS	NS	NS	NS
	R6	NS	-0.49	NS	NS	-0.49	NS	0.37
	R7	NS	NS	NS	NS	-0.52	NS	NS
	R8	NS	-0.42	-0.71	NS	-0.52	NS	NS

[a] NS = not significant.

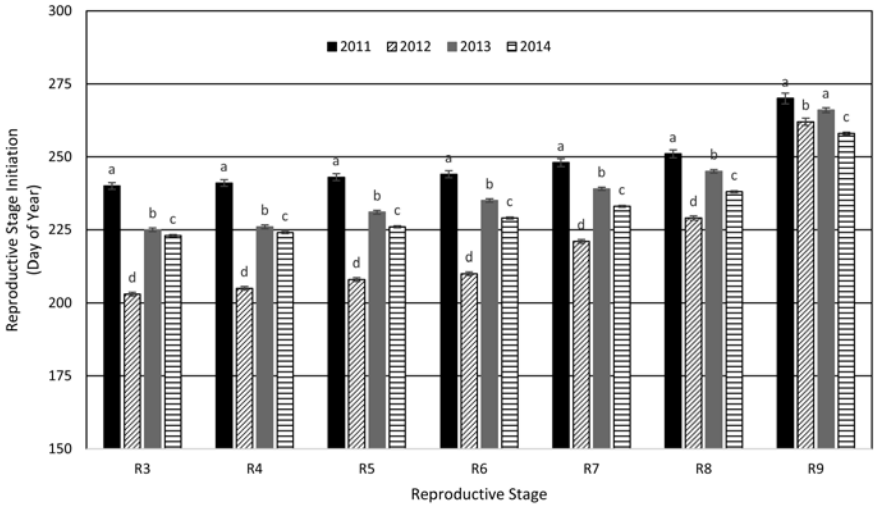

Fig. 1. Average day of year for all cultivars and locations in which each reproductive stage initiated from R3 through R9 across the 2011-2014 growing years. Letters indicate significant differences between years as determined by the Tukey-Kramer honest significant difference test (*P* = 0.05). Bars denote standard error. For reference, days 200, 225, and 250 are 18 July, 13 August, and 7 September, respectively.

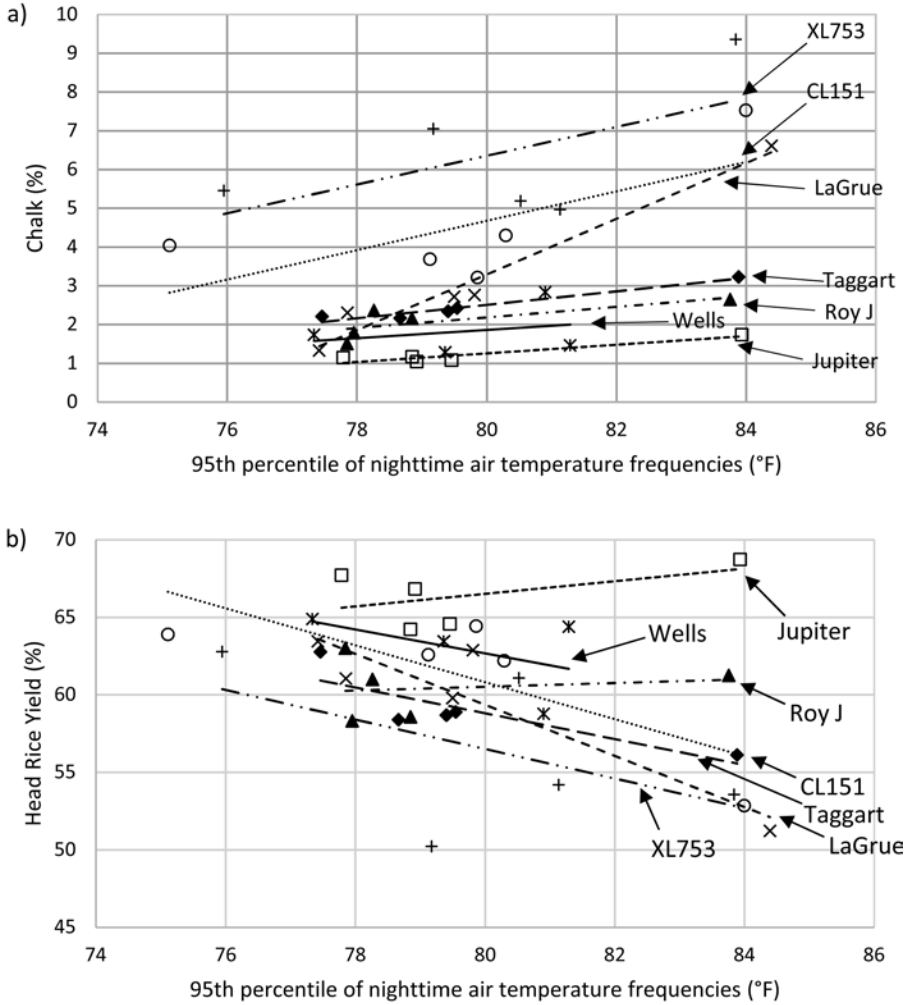

Fig. 2. Relationships of CL151, LaGrue, Jupiter, Taggart, Roy J, Wells, and XL753 in the early/normal heading years of 2012 and 2014 for a) chalk and b) head rice yield with the 95th percentile of nighttime air temperature frequencies during the R8 stage.

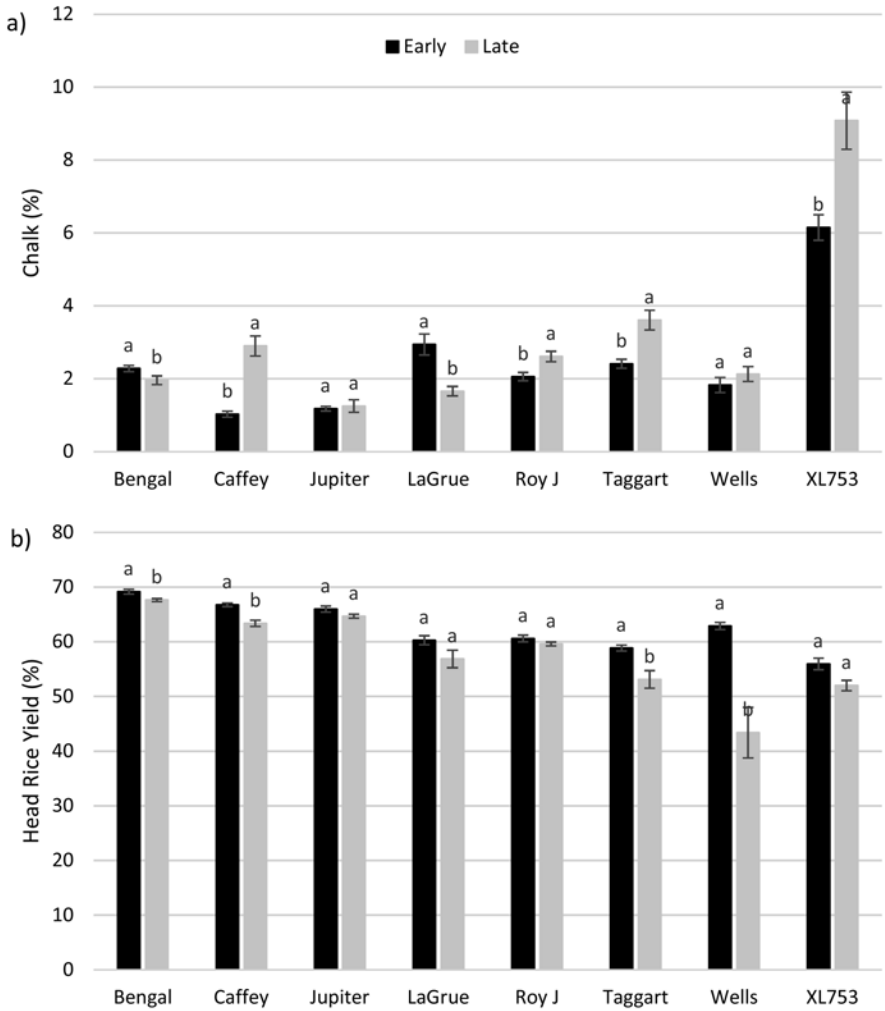

Fig. 3. Impact of early (2012 and 2014) and late (2011 and 2013) heading dates on a) mean chalk and b) mean head rice yield across all growing locations as determined by the Tukey-Kramer honest significant difference test (*P* = 0.05). Bars denote standard error.

Characterization of Broken Rice Kernels Caused by Moisture-Adsorption Fissuring

S. Mukhopadhyay[1] and T.J. Siebenmorgen[1]

ABSTRACT

Fissuring caused by rapid moisture adsorption generates appreciable amounts of broken kernels upon milling, thereby reducing the economic value of rice. This study investigated the extent of kernel fissuring and resultant milling yield reduction in rice lots that had incurred various levels of moisture adsorption-induced fissuring, as well as the physical and functional characteristics of broken kernels that resulted from milling such lots. Roy J, CLXL745, and Jupiter cultivar lots were conditioned to 9%, 11%, 13%, 15%, and 17% initial moisture content (IMC) levels, rewetted in water at 86 °F (30 °C) for 2 h, gently re-conditioned to 12% moisture content (MC), and then milled. Results showed that as IMC prior to rewetting decreased, the extent of fissuring increased, and hence, milling yield decreased. The mass distribution of broken kernels was different between long-grain (LG) and medium-grain (MG) cultivar lots and also between the two LG cultivar lots. Peak and final viscosities were greatest for head rice, and decreased significantly with decreasing size of brokens. Although further investigation of the physical and functional characteristics of broken-kernel fractions is needed before conclusions on practical significance can be drawn, the paste viscosity trends suggest that brokens of different sizes may have different functional properties and hence, may be best suited for different end-use applications.

INTRODUCTION

Moisture-adsorbing environments such as those created by rainfall or high humidity conditions in fields before harvest may induce fissuring in rice kernels of low moisture content (MC). The resultant fissuring causes breakage upon milling, thus reducing milling yield. This can be a common problem faced by rice producers, primarily due to logistical harvesting considerations. Moisture-adsorption fissuring can also occur in post-harvest operations due to inadvertent over-drying and subsequent rewetting of rice.

The recent growth of the pet food industry, wherein brokens are used as an ingredient, as well as the increasing demand for rice flour, which is typically produced

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from brokens, has led to a steady increase in the demand for brokens. While several studies have addressed the impact of rapid moisture adsorption on milling yields, little research was found that investigated the impact on the physical and functional characteristics of broken kernels. Mukhopadhyay and Siebenmorgen (2015) reported the impact of moisture adsorption on the extent of fissuring, as well as the particle-size distribution and functionality of the resultant brokens using one pure-line, long-grain (LG) cultivar, Roy J. The present study was undertaken to expand the findings of Mukhopadhyay and Siebenmorgen (2015). Thus, the objectives were to evaluate the impacts of rapid moisture adsorption on the extent of kernel fissuring and resultant milling yield reduction, as well as to study the physical and functional characteristics of broken kernels generated from multiple rice lots that had incurred various levels of moisture adsorption-induced fissuring.

PROCEDURES

Sample Procurement and Preparation

Figure 1 shows the flowchart for the experiment. Roy J (pure-line, LG), CLXL745 (hybrid, LG), and Jupiter (pure-line, MG) cultivar lots were combine-harvested at Arkansas locations in the fall of 2014 at 17.1%, 19.1%, and 20.6% MC (wet basis, w.b.), respectively. The lots were cleaned and stored in sealed containers at 39 °F (4 °C) for 6 months prior to testing.

For each of the three replicates of this study, 31 lb (14 kg) of clean, rough rice from each cultivar lot was equilibrated to room temperature (~72 °F or 22 °C) for 24 h. Each 31-lb cultivar/replicate lot was divided into six sublots; five, 4.4-lb sublots were conditioned to initial moisture contents (IMCs) of 9%, 11%, 13%, 15%, or 17%, respectively, and a 8.8-lb (4-kg) sublot to 12% IMC (all, ± 0.5 percentage points) in a climate-controlled chamber (5580A, Parameter Generation & Control Inc., Black Mountain, N.C.). For all sublots, the IMC of the conditioned lots was determined by drying duplicate, 15-g subsamples in a convection oven (1370FM, Shellblue, Sheldon Mfg. Inc., Cornelius, Ore.) maintained at 266 °F (130 °C) for 24 h (Jindal and Siebenmorgen, 1987). The 12%-IMC sublots were used as controls.

Rewetting of Samples

To create fissures due to rapid moisture adsorption, each of the 45, 4.4-lb (2-kg) sublots (3 cultivar lots × 5 IMCs × 3 replications) were wrapped in vinyl screen cloth bags and rewetted for 2 h in a water bath (Precision 280, Precision Scientific, Winchester, Va.) at 86 °F (30 °C), then drained for 0.5 h, air-dried at ~72 °F (22 °C) for 1 h, and then re-conditioned to ~12% MC at 79 °F/52% RH (26 °C/52% RH) inside the climate-controlled chamber. The 12%-IMC (control) sublots were not rewetted.

Brown Rice Fissure Enumeration and Determination of Milling Yield

After gently re-conditioning to 12% MC, 300 rough rice kernels were randomly selected from each of the 45 sublots and manually dehulled. Resultant brown rice kernels were visually examined for fissures using a grainscope (TX-200, Kett Electric

Laboratory, Tokyo). Fissured kernels (FK) were enumerated and expressed as a number percentage of the 300 rough rice kernels.

For measurement of milling yield, one, 150-g subsample from each of the 45 re-wetted sublots was dehulled using a laboratory dehuller (THU-35A, Satake Engineering Co., Ltd., Tokyo, Japan) and then milled for the required duration (mentioned below) using a laboratory mill (McGill No.2, Rapsco, Brookshire, Texas) with a 3.3-lb (1.5-kg) mass placed on the lever arm 5.9 in. (15 cm) from the center of the milling chamber. By adjusting the milling duration according to cultivar lot (19 s for Roy J, 25 s for CLXL745, and 24 s for Jupiter), samples were milled to a consistent degree of milling as indicated by a target surface lipid content (SLC) of 0.4%. Milled rice contains head rice (kernels retaining three-fourths or more of their original length) (USDA-FGIS, 2010) and brokens. Milled rice yield (MRY) was quantified as the mass of milled rice, expressed as a percentage of the original, dried rough rice mass. After brokens were removed using a sizing device (61, Grain Machinery Manufacturing Co., Miami, Fla.), head rice yield (HRY) was quantified as the mass of head rice, expressed as a percentage of the original, dried rough rice mass (USDA-FGIS, 2010).

Physical and Functional Characteristics of Broken Kernels

The size distribution of broken kernels was determined using a sieve analysis per ANSI/ASAE Standard S319.6 (1997). A sieve shaker (RO-TAP, RX-29, Mentor, Ohio) with US sieve numbers 10 and 12, having square openings of 0.079 in. (2.00 mm) and 0.066 in. (1.68 mm), respectively, was operated for 15 min, distributing brokens into "large" (retained on the 0.079-in. sieve), "medium" (passed through the 0.079-in. sieve but retained on the 0.066-in. sieve), and "small" (passed through the 0.066-in. sieve) fractions. The 12%-IMC (control) sublots generated negligible amounts of brokens, hence, particle-size distribution and functionality analyses (described below) were not conducted for these sublots.

Peak (PV) and final viscosities (FV) of flour from head rice and the small, medium, and large broken-kernel fractions were determined according to AACCI Method 61-02.01 (1997). From each fraction, 7 g of head rice/broken kernels were ground into flour using a cyclone sample mill (3010-30, UDY Corporation, Fort Collins, Colo.) equipped with a 0.020 in. (0.5-mm) screen. Duplicate 2-g subsamples of flour were dried in the convection oven at 266 °F (130 °C) for 1 h to determine MCs, per AACCI Method 44-15.02 (1975). Adjusted for MC, viscosities were determined on a paste of 3 g of rice flour in 0.007 liquid gal (25 ml) of distilled water using a viscometer (RVA-Super 4, Newport Scientific Pvt. Ltd., Warriewood, NSW, Australia). The flour paste was held at 122 °F (50 °C) for 1.5 min, heated to 203 °F (95 °C) at 12.2 °C/min, held at 203 °F for 2 min, cooled to 122 °F at 12.2 °C/min, and finally held at 122 °F for 1.5 min.

Data Analyses

Statistical analyses were performed (JMP Pro software, Ver. 12.0.1, SAS Institute, Inc., Cary, N.C.). Analysis of variance (ANOVA, $P = 0.05$) was conducted and means separated using Fisher's least significant difference procedure (LSD, $P = 0.05$).

RESULTS AND DISCUSSION

Enumeration of Fissures and Determination of Milling Yield

Figure 2 shows FK, MRY, and HRY for the rewetted sublots. Across all cultivars, IMC had a profound effect on the extent of fissuring and resultant milling yields; as IMC prior to rewetting decreased, the extent of fissuring increased, and HRY correspondingly decreased. At 9% IMC, HRY reached a value of 0%, similar to results of Mukhopadhyay and Siebenmorgen (2013). Thus, the lesser the IMC of the rice when it is rewetted, particularly when IMC decreases below 15%, the greater the extent of fissuring and consequent breakage of kernels when milled, and hence, the more the reduction in HRY.

For all cultivars, MRY decreased with decreasing IMC, although clear statistical differences did not occur until 9%-IMC rice was rewetted. This suggests that with severe fissuring and consequent severe breakage during milling, some endosperm leaves with the bran stream, thus decreasing the total mass of rice produced through milling. These results corroborated the findings of Mukhopadhyay and Siebenmorgen (2013) and Mukhopadhyay and Siebenmorgen (2015). Reduced MRY has economic implications in that both head rice and broken kernels have economic value and thus contribute to the total value of a rice lot.

Physical and Functional Characteristics of Broken Kernels

Figure 3 shows the mass percentages of the broken-kernel fractions. Across all IMCs, the mass percentage of the medium broken-kernel fraction was the greatest for LGs Roy J and CLXL745, whereas the mass percentage of the large broken-kernel fraction was the greatest for MG, Jupiter. The two LGs differed in the mass-distribution of broken-kernel size fractions; for Roy J, it was medium > small > large [corroborating results of Mukhopadhyay and Siebenmorgen (2015)]; whereas for CLXL745, it was medium > large > small. These results indicate that the size-distribution of broken kernels may differ even among LG cultivar lots. For Jupiter, the mass percentages of the broken-kernel fractions were large > medium > small. This knowledge may be useful if processors need to fractionate broken kernels of different sizes for specific purposes.

Figure 4 shows the PV and FV of head rice and the broken-kernel fractions. Some data could not be obtained (indicated by missing bars in Fig. 4) owing to insufficient quantities of samples for analysis using the viscometer. In general, for all cultivars and across all IMCs, both PV and FV were greatest for head rice and decreased significantly with decreasing size of brokens. Thus, regardless of cultivar and IMC prior to rewetting, kernels that broke during milling had different viscosity properties as compared to the kernels that did not break (i.e., head rice).

The paste viscosity trends suggest that brokens of different sizes may have different functional properties. Although statistically significant, further investigation is required to confirm if the differences in the functional properties of the flour obtained from the different broken-kernel fractions are practically significant from a processing/product-formulation/sensory perception standpoint.

SIGNIFICANCE OF FINDINGS

The size-distribution of broken kernels was different between LG and MG cultivar lots and also between the two LG cultivar lots. In general, PV and FV were greatest for head rice, and both decreased significantly with decreasing size of brokens. The paste viscosity trends suggest that brokens of different sizes may differ in their functional properties. This information can be used to ascertain if broken kernels with different physical and functional characteristics should be directed to different end-use applications.

ACKNOWLEDGMENTS

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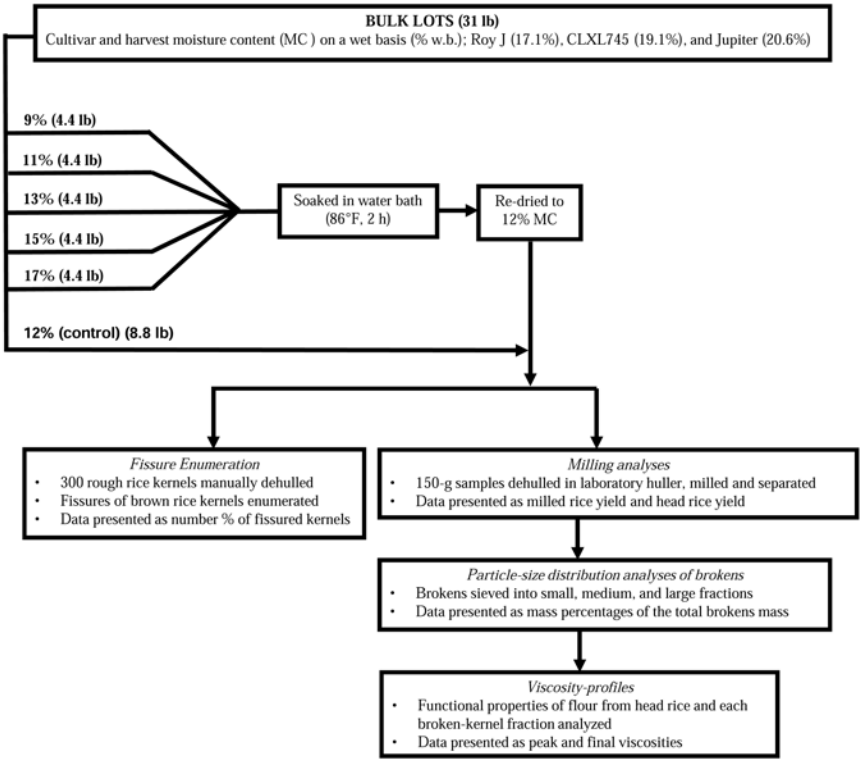

Fig. 1. Process flowchart for the experiment.

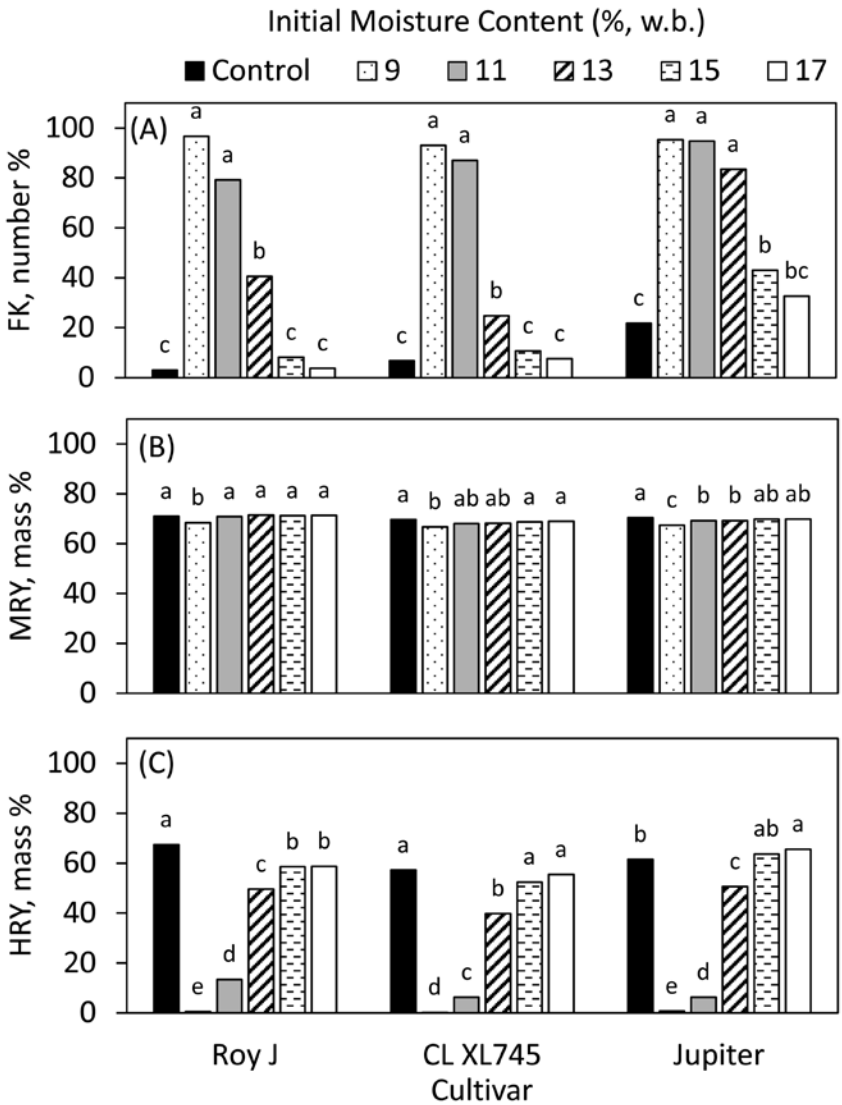

Fig. 2. Fissured kernel percentage (FK) (A), milled rice yield (MRY) (B), and head rice yield (HRY) (C), for the indicated sublots after being conditioned to five initial moisture contents (MCs), rewetted, and conditioned to 12% MC prior to milling. The control (12% IMC) sublots were not rewetted, but rather conditioned from harvest MC to 12% MC prior to milling. Within each cultivar/initial MC set, values followed by the same letter are not significantly different (*P* > 0.05). Bars are based on the mean values of three experimental treatment replications.

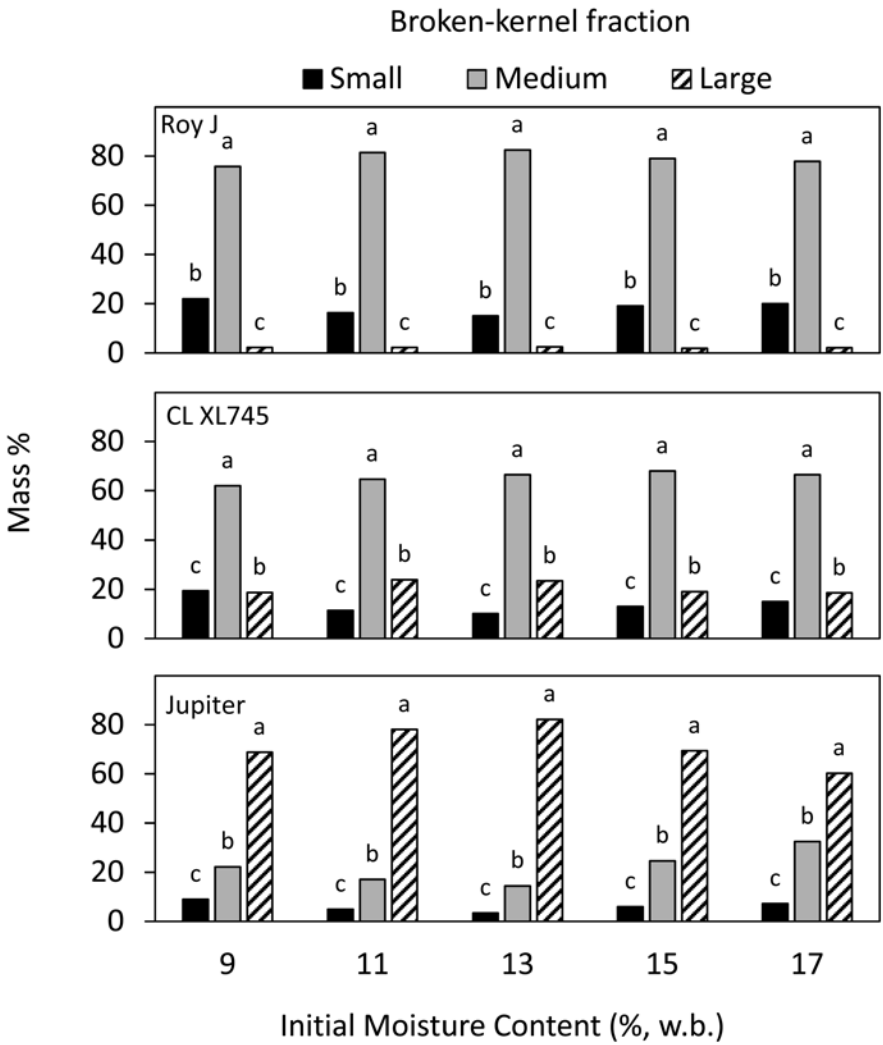

Fig. 3. Mass percentages of small, medium and large broken-kernel fractions for the indicated cultivar sublots after being conditioned to five initial moisture contents (MCs), rewetted, and conditioned to 12% MC prior to milling. Within each IMC/broken-kernel fraction set, values followed by the same letter are not significantly different (*P* > 0.05).

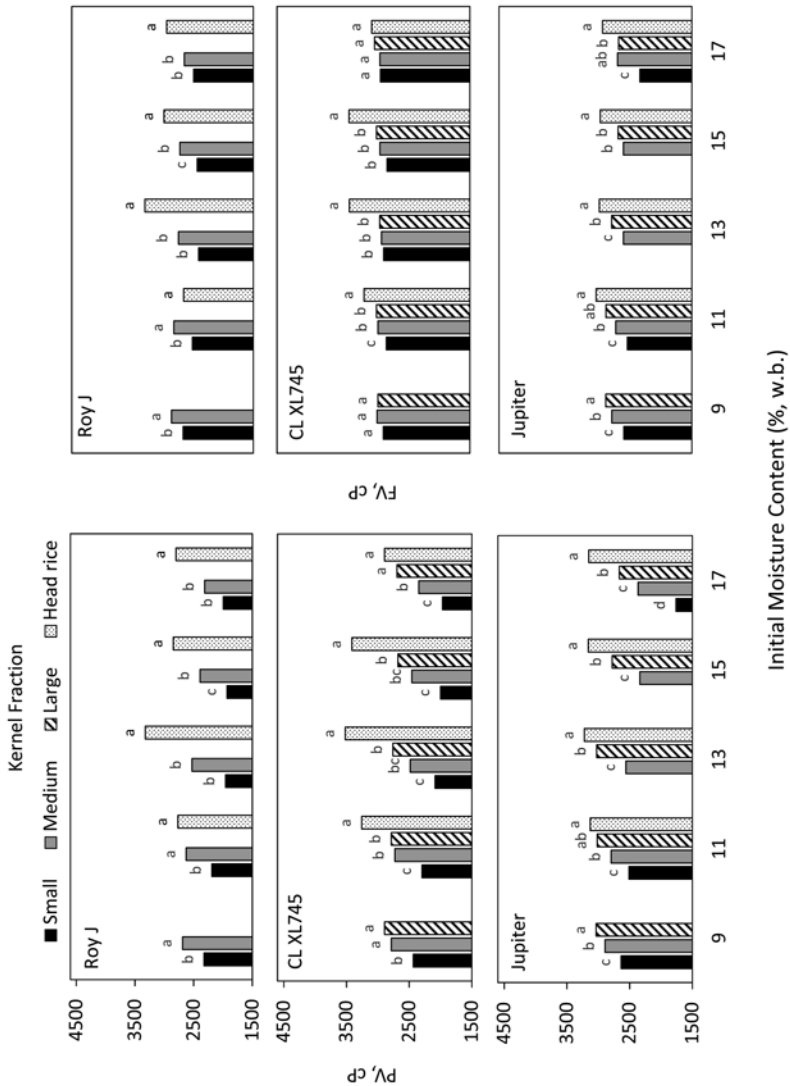

Fig. 4. Peak (PV) and final viscosities (FV) of head rice (HR), small (S), medium (M) and large (L) broken-kernel fractions for the indicated cultivar sublots after being conditioned to five initial moisture contents (MCs), rewetted, and conditioned to 12% MC prior to milling. Within each initial MC/kernel fraction set, values followed by the same letter are not significantly different ($P > 0.05$).

Observing Fissures in Rough Rice Kernels Using X-Ray Imaging: Preliminary Observations

Z.R. Odek[1], B. Prakash[1], and T.J. Siebenmorgen[1]

ABSTRACT

Fissured rice kernels generally break during milling, leading to head rice yield reductions and consequently, large reductions in commercial value. Owing to the fact that there is no rapid method of visualizing fissures in rough rice kernels, the exact mechanism(s) and occurrence of fissuring remains unresolved. While laboratory systems are available to observe fissures in brown and milled rice kernels, these instruments, unfortunately, cannot detect fissures in rough rice, the state in which rice is normally dried. In this manuscript, an instrument for viewing fissures in rough rice kernels using X-rays is presented. The successes, challenges, and other observations experienced during preliminary experimentation are discussed.

INTRODUCTION

Fissured kernels are a major concern in the rice industry due to their susceptibility to breakage during milling, leading to a decrease in head rice yield (HRY; Siebenmorgen et al., 2005). Two general types of fissures are observed in rice kernels: moisture desorption (drying) fissures (Kunze and Prasad, 1978; Schluterman and Siebenmorgen, 2007) and moisture adsorption (rewetting) fissures (Bansazek and Siebenmorgen, 1990; Kunze, 2008). Cnossen and Siebenmorgen (2000) proposed material state differences between the inner core and the endosperm periphery, which cause differential intra-kernel stress, as the main cause of moisture desorption fissures. These fissures are associated with rapid drying and resemble a 'turtle back' pattern appearing in no specific alignment (Stermer, 1968; Bautista et al., 2000). On the other hand, moisture adsorption fissures occur when dry kernels are rapidly rewetted. (Kunze and Hall, 1965). These fissures originate from the center portion of the kernel and progress outwards across the kernel, parallel to the minor axis; these are referred to as "cross-wise" or "straight" fissures (Stermer, 1968; Bautista et al., 2000).

Observation and quantification of fissures in dehulled rice kernels has been possible using instruments such as a grainscope (TX-200, Kett Electric Laboratory, Tokyo,

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Japan; Siebenmorgen et al., 2005) or a video microscopy system (Bautista et al., 2000). A grainscope is a portable instrument that allows for fissure assessment in rice kernels placed on a tray through which light is passed, enabling fissures to be easily observed (Siebenmorgen et al., 2005). On the other hand, a video microscopy system consists of a camera with a 50× magnification lens, luminance controller, and a video recorder allowing for continuous visual monitoring of kernels during drying. Both instruments (grainscope and video microscopy system) are only applicable in brown and milled rice kernels, hence cannot be used to observe fissures in actual drying and tempering, which occurs in the rough rice state with the hulls intact. Therefore, to fully understand fissuring during the drying process, there is need for an alternative method.

X-ray imaging has shown potential for use in achieving this goal. Henderson (1954) used X-ray imaging to develop a drying procedure that would yield maximum HRYs. Menezes et al. (2012), using X-ray imaging, showed a relationship between the degree of fissuring and the germination potential of rice kernels.

Due to the rare use of X-ray imaging as a technique for fissure visualization in rough rice kernels, there are no standard procedures for its application. In addition, with increasing technological advancements, better X-ray imaging systems are being manufactured, which have advanced capabilities. Some of these include the capability of producing digital images, eliminating time that would have been used for film development, being fully shielded to eliminate need for additional X-ray shielding, being easy to operate without specialized X-ray knowledge, and laser centering capability to aid in proper sample positioning. However, depending on the research objectives and the type of X-ray equipment being used, any research involving X-ray imaging involves preliminary experiments aimed at optimizing a particular process. The goal of this overall study is to investigate the fissure occurrence process in rough rice kernels during drying, tempering, and cooling stages. To achieve this goal, there is a need to design an auxiliary system that would allow simulation of the drying, tempering, and cooling processes of rough rice kernels inside an X-ray cabinet while periodically acquiring images. The objectives of the preliminary testing include:

1) Determine a suitable magnification level that would allow for high-resolution visualization of fissures in rough rice kernels.
2) Determine an appropriate orientation of rough rice kernels during X-ray imaging that would allow for visualization of fissures present.
3) Determine a suitable material/holder for use inside the X-ray cabinet to secure and position rough rice kernels without reducing the visual quality of images produced.

PROCEDURES

An X-ray system (UltraFocus 60, Faxitron Bioptics LLC, Tucson., Ariz.) with a maximum sample area dimensions of 10 cm × 15 cm (4 in. × 6 in.) and up to 6× geometric magnification was used for this study. The system produces X-rays with an energy range of 10 to 60 kV, a maximum tube current of 0.3 mA and requires 100 to 200 V, 50/60 Hz to operate. Increasing magnification is achieved by raising an acrylic sample shelf

within the chamber. While increasing the magnification level is often advantageous to improve the image resolution, raising the sample shelf reduces the available field of view, thereby limiting the number of kernels that can be viewed. Therefore, there is a tradeoff between image resolution and available field of view. Figure 1 illustrates the relationship between the magnification level and the available field of view in the X-ray cabinet. As the sample shelf is raised in the X-ray cabinet, the distance between the samples and the X-ray emitter decreases, leading to a decreased field of view.

To determine a suitable magnification for high-resolution fissure observation, long-grain CLXL745 rough rice kernels dried from 18.5% (wet basis) initial moisture content (MC) to a final MC of 12.1% at 140 °F (60 °C) and 12% RH, were placed on the sample shelf at the least magnification (1×) and then an X-ray image was taken. The sample shelf was then raised one level and another X-ray image was taken. This was repeated for all possible magnifications. The images were then visually analyzed and a suitable magnification selected based on the image resolution and number of kernels that could be visualized at each magnification.

In order to determine an appropriate orientation of rough rice kernels that would allow fissure observation, fissured rice kernels were randomly selected. X-ray images of the kernels were taken at 5× magnification with the kernels placed on the sample shelf using two orientations. First, images were taken with the kernels placed on the width side (Fig. 2a), then on the thickness side (Fig. 2b). Using Microsoft Paint (Microsoft Corporation, Redmond, Wash.), the two images were then placed side by side into one viewing frame for ease of comparison. The image was then visually analyzed to determine the appropriate orientation for fissure visualization in rough rice kernels.

In designing a mechanism to hold kernels inside the X-ray cabinet, two design constraints were addressed. Firstly, kernels were to be positioned so as to allow uniform airflow across the kernels, a feature needed for subsequent drying research. Secondly, the material used for the mechanism had to be transparent to X-rays to avoid interference with fissure visualization. Three designs of kernel-positioning mechanism were evaluated. Acrylic was the material of choice for the mechanism since it is transparent to X-rays. The three designs considered for the experiment were, design one which comprised an acrylic plate with cut-out slots slightly larger than the size of a rice kernel, together with a nylon mesh placed below the slots to prevent the kernels from falling over. Design two comprised two acrylic plates one glued on top of the other, with the top plate having cut-out slots and the bottom having drilled holes. Finally, design three comprised an acrylic plate with a 2-mm wide double-sided tape used to secure the kernels. Rough rice kernels were attached to one side of the tape while the other was attached to the acrylic plate. X-ray images using each of the three designs were compared to determine a suitable method for securing and positioning rough rice kernels during image acquisition.

RESULTS AND DISCUSSION

Figure 3 shows a set of X-ray images of rough rice kernels at 1× to 6× magnification. Figure 3 clearly indicates that, as magnification increased, image resolution

increased. However, as magnification increased, the available field of view decreased (Table 1), hence fewer kernels could be visualized.

Of most critical importance to the goal of this work is the need to clearly observe fissures in rough rice kernels. It was observed that 3× to 6× magnification produced high-resolution images in which fissures could be visualized (Fig. 3). Magnification at 4× was deemed to yield an optimal high-resolution X-ray images that clearly show fissures with an adequate field of view, allowing approximately 20 to 30 rough rice kernels to be observed.

Fissures in rough rice kernels were found to be visible in both the width and thickness orientations. Figure 4 shows an X-ray image of five rough rice kernels positioned in both orientations. All fissures visible in the thickness orientation were also visible in the width orientation. However, not all fissures visible in the width orientation were also visible in the thickness orientation. Therefore, placing kernels so as to allow exposure to the width side was deemed appropriate for visualizing fissures in rough rice kernels.

The material used for holding and positioning kernels in the X-ray cabinet influenced the visual quality of the X-ray images. It was observed that density differences of materials within the field of view were greatly amplified by the X-ray images, leading to a reduction in visual quality. Figure 5 shows the effect of density differences of materials within the field of view on the visual quality of X-ray images of rough rice kernels on the cut-out slots and a nylon mesh underneath the kernel-holder, and the cut-out slots with drilled holes underneath the kernel-holder. It was observed in Fig. 5a that the density differences between the acrylic plate, the cut-out slots, and the nylon mesh led to a reduction in the quality of the X-ray image of this kernel-holder design. Fissures that were aligned with the grid lines of the nylon mesh were not clearly visible. As shown in Fig. 5b, density differences caused by the cut-out slots and the drilled holes led to a reduction in the quality of X-ray images of that kernel holder. Figure 6 shows a photograph and an X-ray image of the double-sided tape kernel holder. Using a thin, double-sided tape resulted in minimum density differences and no interferences in the X-ray image quality (Fig. 6b). This approach was deemed to provide a highly suitable method for holding the rough rice kernels both for ease of fissure identification and for allowing uniform air flow around the kernels.

SIGNIFICANCE OF FINDINGS

A 4× magnification with rough rice kernels oriented on their width sides and attached to an acrylic plate using a double-sided tape was considered an appropriate magnification level, kernel orientation, and method of securing/positioning kernels for fissure observation; this combination produced high-resolution images with visibility of fissures in rough rice kernels. This preliminary study serves to provide techniques for visualizing fissures in rough rice kernels. The findings will be applied in designing an auxiliary system that simulates actual rough rice drying, and simultaneously allows visualizing fissures during the drying, tempering, and cooling processes, which will ultimately provide a better understanding of the dynamics of rice fissuring.

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Table 1. Field of view for each level of magnification in the Faxitron UltraFocus 60 X-ray system.

Magnification level	Field of view	
	Metric	English
	(cm × cm)	(in. × in.)
6×	1.7 × 2.5	0.7 × 1
5×	2 × 3	0.8 × 1.2
4×	2.5 × 3.75	1 × 1.5
3×	3.3 × 2	1.3 × 2
2×	5 × 7.5	2 × 3
1.5×	6.7 × 10	2.7 × 4
1×	10 × 15	4 × 6

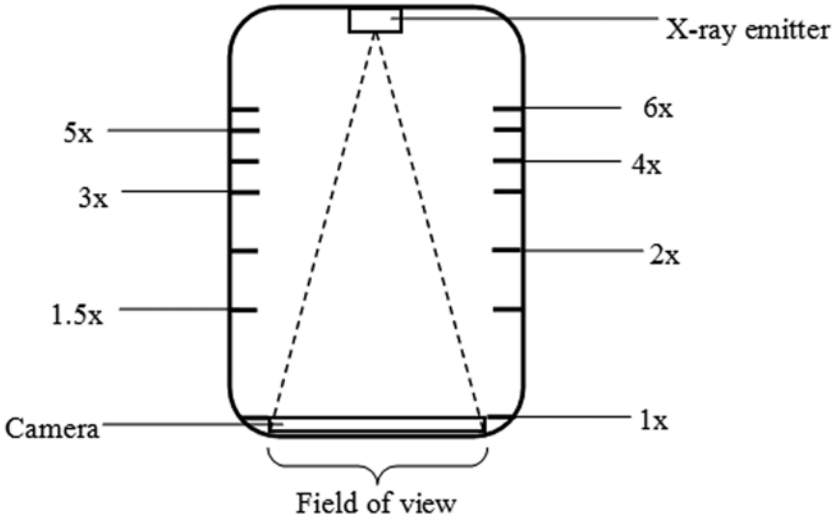

Fig. 1. Illustration of the Faxitron Ultrafocus 60 X-ray cabinet with a decreased field of view as magnification is increased.

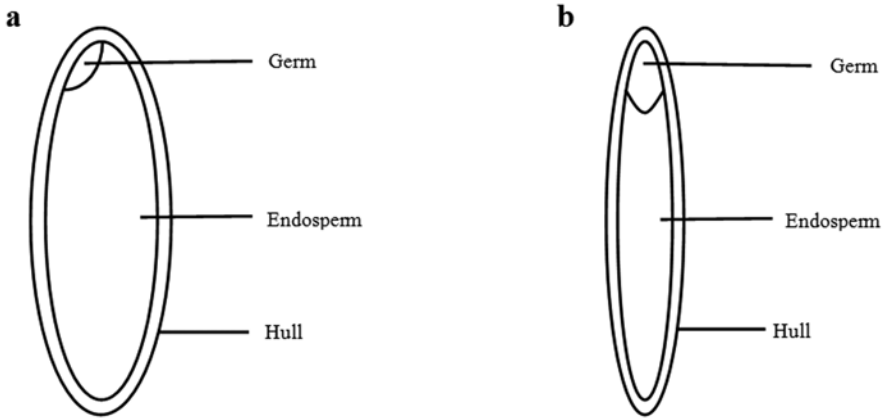

Fig. 2. Illustration of (a) the width-side and (b) thickness-side views of a rough rice kernel.

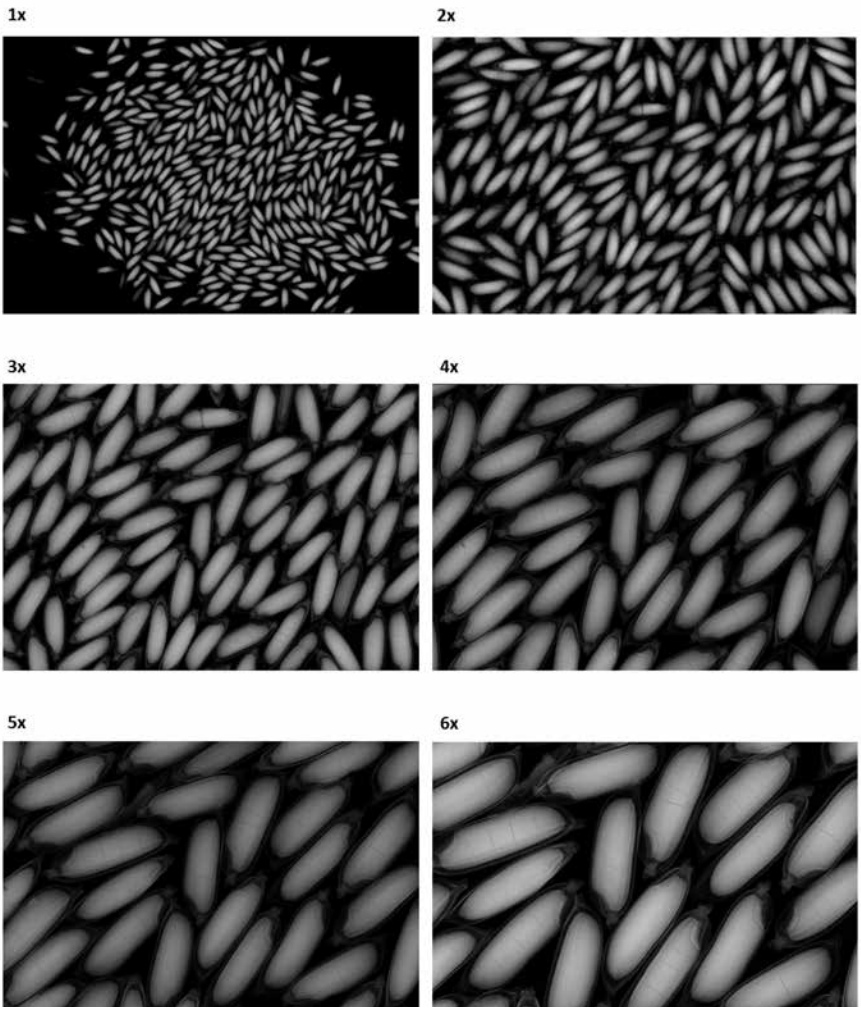

Fig. 3. X-ray images of rough rice kernels at 1×, 2×, 3×, 4×, 5×, and 6× magnifications.

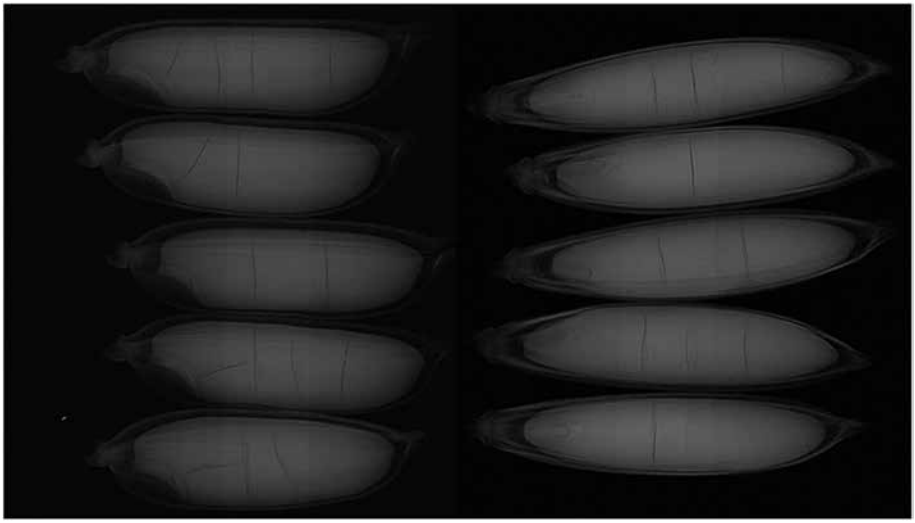

Fig. 4. X-ray images of five rough rice kernels aligned to be viewed in the width (left) and thickness (right) orientations (Fig. 2). All fissures observed in the thickness orientation were also visible in the width orientation but not all in the width orientation were visible in the thickness orientation.

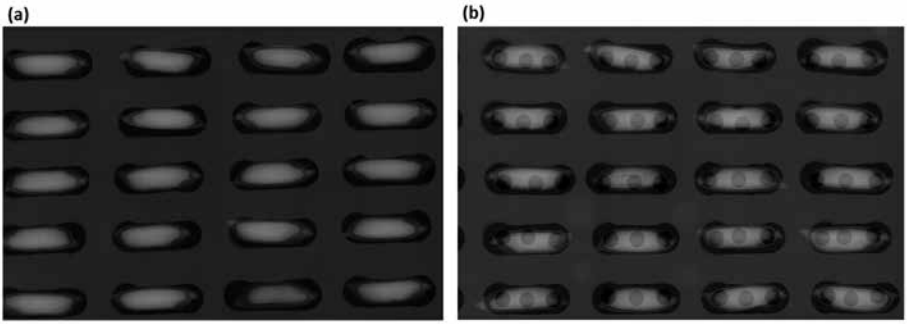

Fig. 5. X-ray images of rough rice kernels on (a) an acrylic plate with cut-out slots and (b) a nylon mesh underneath and in between two acrylic plates, one with cut-out slots and the other with drilled holes. Both show a reduction in visual quality of the images due to density differences of the materials used.

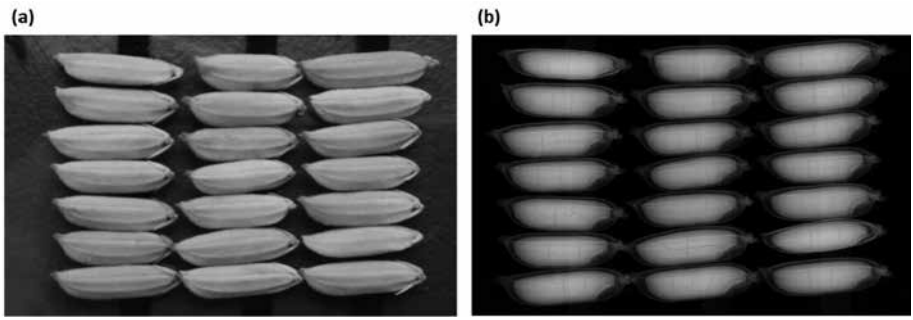

Fig. 6. A (a) photograph and (b) X-ray image of rough rice kernels on a 2-mm wide, double-sided tape secured on an acrylic plate. This method of positioning the kernels caused the least reduction in visual quality of the X-ray images.

Kernel and Starch Properties of United States-Grown and Imported Medium- and Short-Grain Rice Cultivars

J. Patindol[1], J.-R. Jinn[1], Y.-J. Wang[1], and T.J. Siebenmorgen[1]

ABSTRACT

The acreage for medium- and short-grain rice in the mid-southern United States rice-growing region is increasing. This work aimed to identify the quality traits of importance to the markets of these grain types. Twenty-five medium- and short-grain milled rice samples were analyzed for physical, gelatinization, pasting, and starch structural properties. Six samples were from Arkansas (AR), 5 were from California (CA), and 14 were imported (IM) from various countries (Bangladesh, Bhutan, China, India, Italy, Mexico, and Taiwan). Compared to the CA samples, the AR samples had greater kernel yellowness, gelatinization temperature, mineral content, and percentages of B2 and B3 amylopectin chains; but less whiteness, setback viscosity, and percentage of amylopectin A chains. The IM samples had a wide range of physical, functional, and structural characteristics as the samples may be imported to meet the requirements of specific ethnic groups and/or culinary applications.

INTRODUCTION

Combined medium- and short-grain rice production in the United States has been projected to be 2.8 million metric tons for 2016, and accounts for more than one-fourth of the U.S. rice production (Childs, 2015). Since 2014, the mid-South rice-growing regions have attained a larger-than-normal share of U.S. medium- and short-grain rice production due to reduced acreage in California and consequent water shortages. Export and import forecast for these grain types are 1.7 and 0.2 million metric tons, respectively, and imports account for ~11% of the U.S. medium- and short-grain rice domestic consumption (Childs, 2015). Northeast Asia, North Africa, and the Middle East are significant export markets for U.S. medium- and short-grain rice (Childs, 2015). Domestically, U.S. medium- and short-grain cultivars are preferred for breakfast cereals, pudding, baby food, and brewing. Calrose-type cultivars are generally used in making California rolls and localized sushi products (Bryant et al., 2013; Marton,

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2014). Medium-grain rice is the primary staple of various consumers in Asia, Australia, Africa, Italy, Latin America, and the Caribbean (Calingacion et al., 2014). Some Asian countries (e.g., Bangladesh, Sri Lanka, and China) grow aromatic, short-grain varieties with very small round grains that are highly prized and bring premiums on local markets (Efferson, 1985).

This work compared the kernel physicochemical properties and starch structural features of medium- and short-grain rice cultivars grown in Arkansas with those grown in California, and with samples imported from different regions of the world. The primary goal is to gain a better understanding of the fundamental grain quality traits of importance to the medium- and short-grain rice markets.

PROCEDURES

Rice Samples

The milled rice sample set consisted of 6 samples from Arkansas (AR), 5 samples from California (CA), and 14 samples imported (IM) from various countries (Bangladesh = 1, Bhutan = 1, China = 5, India = 1, Italy = 1, Mexico = 1, and Taiwan = 4). All AR samples were obtained as rough rice from the 2014 crop (3 foundation seeds and 3 breeding lines) and milled in the laboratory. Milled rice samples from China and Taiwan were gifts from a research colleague; all other samples were purchased from grocery or specialty stores in the northwest Arkansas area during the first quarter of 2015. The Arkansas samples were milled to a target surface lipid content of 0.4% and whole kernels (head rice) were separated from broken kernels using a double-tray shaker.

Physical Qualities

Chalk measurements were performed on duplicate, 100-kernel milled rice samples using an image analysis system (WinSEEDLE™ Pro 2005a, Regent Instruments, Quebec, Canada). Head rice color was measured using a colorimeter (ColorFlex, Hunter Associates Laboratory, Reston, Va.). Kernel dimensions (length, width, and thickness) were measured on ~1000 kernels using a SeedCount 5000 digital image analysis system (Next Instruments, New South Wales, Australia). Surface lipid content was determined according to AACC Method 30-20 (AACC International, 2000) with modifications by Matsler and Siebenmorgen (2005).

Chemical Components

Milled rice flour samples were obtained by grinding in a laboratory mill (cyclone sample mill, Udy Corp., Ft. Collins, Colo.) to pass through a 0.5-mm sieve. Apparent amylose content was determined by iodine colorimetry; moisture content by the oven-drying method; total protein by the micro-kjeldahl method; and mineral content by the dry-ashing method. Starch was prepared from milled rice flour by extraction with dilute

alkali (0.1% NaOH) followed by lipid removal with water-saturated n-butyl alcohol (Patindol and Wang, 2002). Amylopectin chain-length distribution was characterized by high-performance anion-exchange chromatography with pulsed amperometric detection (HPAEC-PAD) using isoamylase-debranched starch samples (Patindol et al., 2014).

Gelatinization and Pasting Characteristics

Milled rice flour gelatinization properties were assessed with a differential scanning calorimeter (DSC, Pyris Diamond, Perkin Elmer Instruments, Shelton, Conn.). Flour pasting properties were determined with a Rapid Visco-Analyser (RVA model 4, Perten Instruments, Springfield, Ill.). Rice flour slurry was prepared by mixing 0.11 oz (3.0 g) of rice starch (12% moisture content basis) with 0.85 oz (25.0 mL) of deionized water and heated from 122 °F to 203 °F (50 °C to 95 °C) at 52 °F (11.2 °C)/min, held at 203 °F (95 °C) for 2.5 min, cooled to 122 °F (50 °C) at 11.2 °C/min, and held at 50 °C for 1.0 min.

RESULTS AND DISCUSSION

Table 1 presents the ranges and means for the kernel and starch properties of the 25 milled rice samples. The kernel images of 8 representative samples are shown in Fig. 1. Kernel dimension measurements showed that the AR and CA samples were comparable in length, width, and thickness (Table 1). Those of the IM samples varied widely, with length-to-width ratios that ranged from 1.6 to 2.8. Based on Federal Grain Inspection Service (FGIS) standards, milled rice may be classified according to kernel length-to-width ratio as long (≥3.0), medium (2.0-2.9), or short (≤1.9) (USDA, 2014). Only 12 of the 25 samples were medium-grain type 4 AR, 4 CA, and 4 IM, and the rest were short-grain. The AR samples tended to have less whiteness and greater yellowness than the CA samples; the IM samples had whiteness and yellowness values that varied widely. Percent chalk ranged from 0.6% to 59.2%; it was highest for Arborio, a sample imported from Italy and least for a sample (no cultivar name) imported from China. The percent chalk of the United States-grown samples was less than 6%, except for one CA sample (Haitai brand), in which the percent chalk was 13.7%.

The onset gelatinization temperature (GT) of most samples was below 70 °C (Table 1), with exception of Taichung 11 (from Taiwan, onset GT = 165.9 °F; 74.4 °C) and Sona Masoori (from India, onset GT = 161.1 °F; 71.7 °C). The CA samples had the narrowest range of gelatinization properties, whereas the AR samples had slightly greater GT parameters (onset, peak, end, and range) than the CA samples by at least 1 °C.

A wider range of pasting characteristics was observed in the IM samples than the locally grown cultivars (Table 1). Figure 2 shows the pasting profiles of 8 representative samples, including AR samples of Jupiter and Caffey. Some samples with unique pasting properties were noted. Morelos (from Mexico) had the highest peak (3838 cP) and final (5613 cP) viscosities. Sona Masoori had a very low peak (1832 cP) and breakdown (16 cP) viscosities, and a very high setback (2411 cP). Tainong-71 (from

Taiwan) had a very high breakdown viscosity (1965 cP). All AR and CA samples had negative setback viscosities. Between AR and CA samples, the AR samples tended to have higher peak and lower setback and total setback viscosities.

Amylose content was comparable among AR and CA samples, whereas that of the IM samples varied widely (Table 1). Five samples had an amylose content of ≥20% (Taichung 1, Morelos, Bhutan, Sona Masoori, and Kalijira), and the rest had an amylose content of ≤18%. Protein content varied widely among IM samples, but was comparable among AR and CA samples. Total ash (mineral) content was below 1.0%, and tended to be greater for the AR samples. Amylose content correlated positively with onset GT, peak viscosity, setback, and total setback; and negatively with gelatinization range and breakdown (Table 2). Protein correlated positively with yellowness, and mineral content correlated positively with percent chalk only.

Amylopectin chain-length distribution analysis revealed a wide range of variation in the percentages of A, B1, B2, and B3 chains among IM samples (Table 1). The AR samples had lesser percentages of A chain and greater percentages of B2 and B3 chains, in comparison with the CA samples. Correlation analysis showed that A chain correlated negatively with GT, final viscosity and setback; and positively with GT range and paste breakdown (Table 2). The B1 chain correlated positively GT, final viscosity, setback, and total setback; and negatively with GT range, peak viscosity, and breakdown. The B2 chain poorly correlated with any quality attribute. The B3 chain positively correlated with GT and peak viscosity.

SIGNIFICANCE OF FINDINGS

Producing rice that can satisfy domestic and/or export market demands is the key to a successful and competitive Arkansas rice industry. Findings from this research are useful to farmers in choosing specific cultivars to plant, to rice breeders in knowing the traits/markers to include in varietal improvement efforts, and to processors in optimizing processing operations to consistently produce high-quality milled rice and/or derived products.

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Table 1. Ranges and means for the kernel properties of United States-grown and imported medium- and short-grain rice cultivars.

Kernel property	Range [Mean] according to sample origin		
	Arkansas (n = 6)[a]	California (n = 5)[a]	Imported (n = 14)[a]
Appearance			
Length (mm)	5.4-5.8 [5.6]	5.0-5.8 [5.6]	4.1-6.6 [5.2]
Width (mm)	2.7-3.0[2.9]	2.9-3.0 [2.9]	1.9-3.6 [2.9]
Thickness (mm)	2.1-2.2 [2.1]	2.0-2.2 [2.1]	1.4-2.5 [2.1]
Length/Width	1.9-2.1 [2.0]	1.7-2.0 [1.9]	1.6-2.8 [1.9]
Whiteness (L*)	64.9-71.8 [69.7]	70.2-74.2 [72.2]	70.5-76.1 [73.5]
Yellowness (b*)	14.4-20.1 [16.2]	14.0-16.7 [15.7]	10.3-18.1 [14.4]
Chalk (% by area)	1.9-5.1 [3.2]	1.5-13.7 [4.7]	0.6-59.2 [14.3]
Gelatinization property			
Onset GT (°F)	149-153 [150]	145-147 [146]	125-166 [148]
Peak GT (°F)	161-165 [162]	156-157 [157]	149-172 [159]
Range (°F)	55-58 [56]	52-57 [55]	46-64 [55]
Enthalpy (J/g)	10.3-14.2 [11.7]	8.9-11.6 [10.9]	8.4-11.8 [10.4]
Pasting property[b]			
Peak viscosity (cP)	3163-3727 [3414]	3031-3275 [3168]	1832-3838 [2984]
Final viscosity (cP)	2726-2946 [2855]	2760-2942 [2854]	2651-5613 [3631]
Breakdown (cP)	1329-1965 [1588]	1465-1710 [1582]	16-1947 [1152]
Setback (cP)	(-811)-(-416) [-599]	(-415)-(-197) [-315]	(-760)-2411 [647]
Total setback (cP)	913-1154 [1029]	1194-1352 [1267]	1187-2757 [1799]
Gross composition			
Amylose (%)	9.5-14.4 [12.4]	12.7-15.1 [13.4]	11.6-25.5 [17.4]
Protein (%)	5.6-6.9 [6.4]	5.7-6.7 [6.2]	4.4-8.0 [6.4]
Mineral (%)	0.33-0.58 [0.44]	0.25-0.55 [0.38]	0.22-0.51 [0.38]
Amylopectin structure[c]			
A Chain (%)	26.6-27.3 [26.8]	27.5-28.0 [27.7]	22.4-28.8 [26.5]
B1 Chain (%)	45.1-46.5 [46.0]	46.1-46.6 [46.3]	46.0-51.3 [47.6]
B2 Chain (%)	13.7-14.3 [14.0]	13.2-13.6 [13.4]	12.8-14.1 [13.4]
B3 Chain (%)	13.0-13.4 [13.2]	12.3-12.8 [12.6]	12.0-13.2 [12.5]

[a] *n* = sample size; GT = gelatinization temperature.

[b] Calculation: Breakdown = Peak viscosity minus - Trough; Setback = Final viscosity - Peak viscosity; Total setback = Final viscosity - Trough.

[c] Amylopectin chains: A chain, 6-12 glucose units; B1 chain, 13-24 glucose units; B2 chain, 25-36 glucose units; B3 chain, 37-65 glucose units.

Table 2. Correlation coefficients for the relationship of appearance/functional properties with kernel chemical components and amylopectin fine structure (n = 25)[a].

	Amylose	Protein[b]	Mineral	A Chain[c]	B1 Chain	B2 Chain	B3 Chain
Whiteness	0.43*[d]	-0.17[ns]	-0.16[ns]	-0.08[ns]	0.25[ns]	-0.37[ns]	-0.29[ns]
Yellowness	-0.10[ns]	0.53**	0.02[ns]	0.09[ns]	-0.10[ns]	-0.08[ns]	0.10[ns]
Chalkiness	0.27[ns]	0.23[ns]	0.40*	-0.13[ns]	0.19[ns]	-0.21[ns]	-0.02[ns]
Onset GT[e]	0.44*	-0.04[ns]	-0.05[ns]	-0.86**	0.59**	0.31[ns]	0.60**
Peak GT	0.38[ns]	-0.02[ns]	-0.02[ns]	-0.84**	0.57**	0.32[ns]	0.60**
Range	-0.52**	0.10[ns]	0.12[ns]	0.66**	-0.54**	0.07[ns]	-0.33[ns]
Enthalpy	-0.07[ns]	-0.35[ns]	0.29[ns]	-0.15[ns]	0.06[ns]	0.21 [ns]	0.14[ns]
Peak viscosity	-0.34[ns]	-0.16[ns]	0.30[ns]	0.12[ns]	-0.41*	0.53**	0.54**
Final viscosity	0.73**	0.06[ns]	0.02[ns]	-0.63**	0.60**	-0.11[ns]	0.17[ns]
Breakdown	-0.70**	-0.12[ns]	0.24[ns]	0.54**	-0.65**	0.32[ns]	0.12[ns]
Setback	0.83**	0.13[ns]	-0.12[ns]	-0.64**	0.74**	-0.36[ns]	-0.10[ns]
Total setback	0.83**	0.12[ns]	-0.01[ns]	-0.63**	0.73**	-0.35[ns]	-0.08[ns]

[a] n = sample size.
[b] ns = not significant at 95% probability ($P < 0.05$; n = 25).
[c] Amylopectin chains: A chain, 6-12 glucose units; B1 chain, 13-24 glucose units; B2 chain, 25-36 glucose units; B3 chain, 37-65 glucose units.
[d] * = Significant at 95% probability ($P < 0.05$; n = 25); ** = Significant at 99% probability ($P < 0.01$; n = 25).
[e] GT = gelatinization temperature.

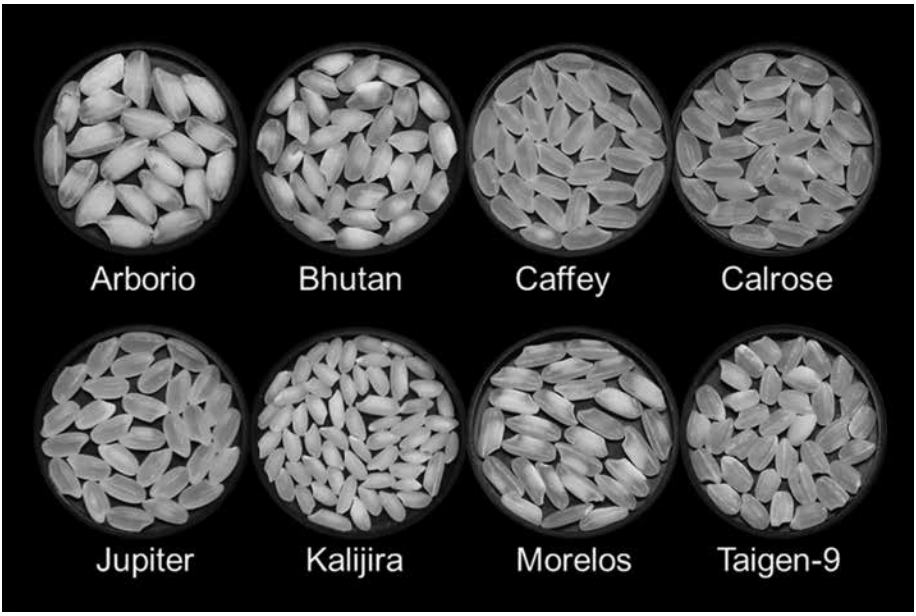

Fig. 1. Milled rice kernels of some locally grown and imported medium- and short-grain rice cultivars: Arborio (Italy), Bhutan (Bhutan), Caffey (Arkansas), Calrose (California), Jupiter (Arkansas), Kalijira (Bangladesh), Morelos (Mexico), and Taigen-9 (Taiwan).

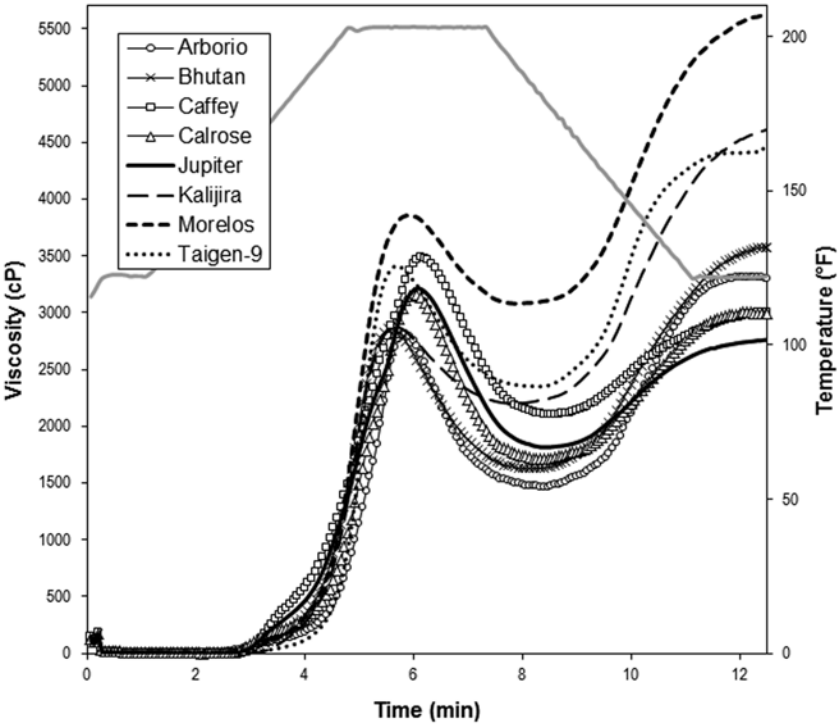

Fig. 2. Flour pasting profiles of Jupiter (from Arkansas) and seven other medium- and short-grain milled rice samples.

Trans-Pacific Partnership: What Can it Mean for the U.S. Rice Sector?

A. Durand-Morat[1] and E.J. Wailes[1]

ABSTRACT

We assess the impact of the negotiated rice market access outcome of the Trans-Pacific Partnership (TPP) and the initial request by the U.S. regarding market access to the Japanese rice market. The results suggest the impact of TPP will be limited, resulting in expansion of intra-TPP trade to the benefit of the U.S. and Vietnam.

INTRODUCTION

Negotiations on the Trans-Pacific Partnership (TPP) concluded on October 2015 after more than 5 years of intensive negotiations primarily on a few key sectors, including rice (Honma, 2015). As a sensitive sector, the motivation for this study is to better understand the economics negotiated outcome on rice between Japan and the U.S. The objective is to assess the impact of TPP on the global and regional rice markets. It complements current literature (e.g., Burfisher et al., 2014; Government of Japan, 2013) in two ways. First, our modeling framework disaggregates rice markets by type and milling degrees, allows for imperfect substitution of imports and domestic production, and incorporates key trade policies affecting rice markets. Finally, we calibrate the model for 2013, to represent the current global rice economy.

Rice trade among TPP members in 2013 was 41.8 million cwt (1.9 million metric tons, mmt), milled basis, 5.3% of global rice trade. The effective import tariff of TPP member import policies in 2013 is 72%, primarily affecting trade of medium-grain rice. Japan has the highest level of protection among TPP members, trailed by Malaysia and Chile.

Most TPP partners grant low most-favored-nation (MFN) protection to all exporters into their rice markets, thereby generating minimal trade distortions (WTO-TAO, 2015). For instance, Australia, Brunei, Canada, New Zealand, and Singapore maintain zero MFN import tariffs on rice. Chile, the U.S., and Vietnam apply low import tariffs (below 10%). Mexico reinstated a 9% import tariff on paddy rice and 20% import tariff on brown and milled rice since December 2014 (USDA/FAS, 2014) after years of

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duty-free imports from all sources. Imports of U.S. rice into Mexico remain duty free under the North American Free Trade Agreement (NAFTA). Peru maintains a price band system intended to stabilize domestic prices within set bounds.

Japan has historically maintained high market prices and rice farm incomes through trade protection, income support programs, and domestic diversion programs (Takahashi and Honma, 2015), and currently keeps a tariff-rate-quota (TRQ) of 15.0 million cwt (682 thousand metric tons, tmt), milled basis with an over-quota tariff set at the prohibitive level of US$2.90/Kg (¥ 341/kg). The TPP deal reached with Japan, which includes country-specific TRQs with Australia and the U.S. is the most contentious aspect of the negotiated outcome for rice (Table 1).

PROCEDURES

We use the RiceFlow model (Durand-Morat and Wailes, 2010) to assess the impact of TPP on the global rice economy. RiceFlow is a spatial, supply-chain model of the global rice economy. The model disaggregates the rice economy into 73 regional markets and 9 rice commodities derived from the combination of rice type (long, medium, and fragrant rice) and milling degree (paddy, brown, and milled rice).

We assume imperfect substitution between imports and domestic rice consumption (Hertel et al., 2003). Previous studies show that Japanese consumers prefer domestic over imported rice (Peterson et al, 2013; Aizaki, 2015). For more details of the model specification see Durand-Morat and Wailes (2016). The model is simulated dynamically through 2029, with each subsequent year dependent on the previous year's outcome. By 2029 we assume TPP will reach full implementation.

Scenarios

A benchmark scenario projects the international rice market up to year 2029 based on assumptions on key exogenous variables including rice yields, population, gross domestic product, and policies. Projected rice yields are obtained from FAPRI (2015). Macroeconomic projections are obtained from IHS Global Insight (2015).

In 2013 the Government of Japan introduced the Plan to Create Vitality for Agricultural, Forestry, and Fishery Industries and Local Communities (The Plan), aimed at increasing the competitiveness of Japanese agriculture (OECD, 2014). We implement in the model changes introduced by The Plan to define some of the following scenarios:

- TPP1: assumes the TPP Agreement is implemented as negotiated starting in 2017.
- TPP2: assumes the TPP Agreement is implemented as negotiated starting in 2017 by all countries, except that Japan grants a 4.4 million cwt (200 tmt) TRQ to the U.S. as follows: 1.1 million cwt (50 tmt) from year 1 to 3, and annual increases of 0.33 million cwt (15 tmt) up to 4.4 million cwt (200 tmt) by year 2029. This scenario approximates the initial U.S. negotiation request of Japan rice market access.

- TPP1R: in addition to assumptions of scenario TPP1, we assume that domestic rice policy reforms in Japan advance as expected but result in no improved rice farm productivity.
- TPP2R: in addition to assumptions of scenario TPP2, we assume that domestic rice policy reforms in Japan advance as expected but result in no improved rice farm productivity.
- TPP1RE: in addition to assumptions of scenario TPP1, we assume that domestic rice policy reforms in Japan generate a positive impact on rice farm productivity. We assume that policy reforms result in larger farms (Takahashi and Honma, 2015) and decrease rice production costs by 8.5% over 5 years (from 2018 to 2023).
- TPP2RE: in addition to assumptions of scenario TPP2, we assume that the rice reforms in Japan generate the same effect on productivity as that estimated in scenario TPP1RE.

RESULTS AND DISCUSSION

Impacts of TPP on the global rice market compared to the benchmark are projected to be limited for three reasons: the small amount of trade among TPP members relative to global trade, the already high level of trade integration among many of its members, and the limited trade concessions granted by Japan (Table 2).

The TPP is projected to have an impact on rice supply and demand aggregates across the TPP region, increasing intra-regional rice trade above benchmark growth by 0.93% and 1.14% a year as a result of TPP1 and TPP2, respectively (Table 2). Total exports and imports by TPP members increase as a result of the agreement. In nominal terms, TPP1 and TPP2 project an increase of rice exports from the U.S. by 0.77 thousand cwt (35 tmt) and 2.09 million cwt (95 tmt) a year, respectively, when fully implemented. The Japanese rice policy reforms have negligible spillover effects onto the region.

The U.S. gains from the TPP agreement on rice, primarily in the medium-grain segment. Results project a steady increase in U.S. rice production of 1.46% annually in the benchmark from 2014 to 2029, which strengthens slightly up to 1.56% as a result of TPP2 (Table 3). The TPP promotes the production of medium-grain rice at the expense of long-grain rice (Fig. 1). United States rice consumption is expected to remain unchanged across the scenarios analyzed, which means that the increased production will go entirely for export.

Medium- and short-grain rice production is increasing in the mid-South, primarily in Arkansas where it reached 16.5 million cwt (750 tmt) in 2014. United States medium- and short-grain production increases in response to increasing productivity. We assume that medium-grain from the mid-South will have the same acceptance in markets overseas as that from California. Based on the 2015 crop budgets for rice from the University of California and the University of Arkansas Cooperative Extension, and transportation cost data from private industry sources, we estimate the medium-grain rice cost advantage of mid-South compared to California into Japan to be around $200/ton. This leads us to conclude that, conditional on similar consumer acceptance,

switching medium-grain production to the mid-South results in significant gains in price competitiveness for U.S. medium-grain rice.

SIGNIFICANCE OF FINDINGS

The TPP initiative stands as a great opportunity to advance trade integration and generate sizable benefits to its members. However, the impact of the negotiated TPP outcome for rice is expected to be small for the U.S. rice sector as a whole. The gains accrue primarily to the medium- and short-grain segment, conditional on the ability to expand exports of high quality medium-grain with acceptance into the Japanese market. We estimate no sizable gains for the U.S. long-grain sector as a result of TPP. We acknowledge the concerns generated by increasing price competitiveness of Vietnamese long-grain rice in several Western Hemisphere markets such as Mexico, although currently poor rice quality is likely the main constraint facing Vietnamese rice in the Western Hemisphere markets participating in TPP.

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Table 1. Country-specific Tariff Rate Quota granted by Japan to Australia and the U.S. in the Trans-Pacific Partnership (TPP).

	Quota Country-specific Tariff Rate Quota	
Year[a]	**U.S.**	**Australia**
	-------- (million cwt) ---------	
1	1.10	0.13
2	1.10	0.13
3	1.10	0.13
4	1.14	0.14
5	1.19	0.14
6	1.23	0.15
7	1.28	0.15
8	1.32	0.16
9	1.36	0.16
10	1.41	0.17
11	1.45	0.17
12	1.50	0.18
13	1.54	0.18

[a] For Year 14 and for each subsequent year, the aggregate quota quantity shall remain at the level reached in Year 13. Source: TPP Full Text available at https://ustr.gov/trade-agreements/free-trade-agreements/trans-pacific-partnership/tpp-full-text

Table 2. Average 2015-2029 annual change in global and regional rice production, consumption, and trade by various Trans-Pacific Partnership (TPP) scenarios.

	Bench	TPP1[a]	TPP1R[b]	TPP1RE[c]	TPP2[d]	TPP2R[e]	TPP2RE[f]
Global production	0.67%	0.67%	0.67%	0.67%	0.67%	0.67%	0.67%
LG[g]	0.73%	0.73%	0.73%	0.73%	0.73%	0.73%	0.73%
MG	0.13%	0.13%	0.13%	0.13%	0.13%	0.13%	0.13%
FR	1.21%	1.21%	1.21%	1.21%	1.21%	1.21%	1.21%
Global consumption	0.68%	0.68%	0.68%	0.69%	0.69%	0.69%	0.69%
LG	0.75%	0.75%	0.75%	0.75%	0.75%	0.75%	0.75%
MG	0.14%	0.13%	0.13%	0.14%	0.13%	0.13%	0.14%
FR	1.03%	1.03%	1.03%	1.03%	1.03%	1.03%	1.03%
Global trade	2.09%	2.10%	2.10%	2.10%	2.12%	2.12%	2.12%
LG	2.22%	2.22%	2.22%	2.22%	2.22%	2.22%	2.22%
MG	0.86%	1.10%	1.10%	1.10%	1.48%	1.48%	1.48%
FR	1.61%	1.62%	1.62%	1.62%	1.62%	1.62%	1.62%
TPP production	0.4%	0.4%	0.4%	0.4%	0.4%	0.4%	0.4%
TPP consumption	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%
TPP intra trade	1.9%	3.0%	3.0%	3.0%	3.3%	3.3%	3.3%
TPP member exports	2.2%	2.4%	2.4%	2.4%	2.4%	2.4%	2.4%
TPP member imports	1.7%	1.9%	1.9%	1.9%	2.1%	2.1%	2.1%

[a] Scenario TPP1: it assumes the TPP Agreement is implemented as negotiated starting in 2017.

[b] Scenario TPP2: it assumes the TPP Agreement is implemented as negotiated starting in 2017 by all countries, except that Japan grants a 4.4 million cwt (200 tmt) TRQ to the U.S. as follows: 1.1 million cwt (50 tmt) from year 1 to 3, and annual increases of 0.33 million cwt (15 tmt) up to 4.4 million cwt (200 tmt) by year 2029. This scenario approximates the initial U.S. negotiation request of Japan rice market access.

[c] Scenario TPP1R: in addition to assumptions of scenario TPP1, we assume that domestic rice policy reforms in Japan advance as expected but result in no improved rice farm productivity.

[d] Scenario TPP2R: in addition to assumptions of scenario TPP2, we assume that domestic rice policy reforms in Japan advance as expected but result in no improved rice farm productivity.

[e] Scenario TPP1RE: in addition to assumptions of scenario TPP1, we assume that domestic rice policy reforms in Japan generate a positive impact on rice farm productivity. We assume that policy reforms result in larger farms (Takahashi and Honma, 2015) and decrease rice production costs by 8.5% over 5 years (from 2018 to 2023).

[f] Scenario TPP2RE: in addition to assumptions of scenario TPP2, we assume that the rice reforms in Japan generate the same effect on productivity as that estimated in scenario TPP1RE.

[g] LG: long-grain rice. MG: medium- and short-grain rice. FR: fragrant rice.

Table 3. United States supply and demand situation at the end of the implementation of Trans-Pacific Partnership (TPP)[a].

	Baseline	TPP1	TPP2
Production			
2029 Level (million cwt)	174.6	175.4	176.8
Av.An.Chg[b]	1.46%	1.50%	1.56%
Consumption			
2029 Level (million cwt)	104.1	104.1	104.1
Av.An.Chg	1.30%	1.30%	1.30%
Net exports			
2029 Level (million cwt)	81.3	82.5	84.4
Av.An.Chg	1.46%	1.56%	1.73%

[a] The scenarios incorporating the impact of the reforms to the Japanese rice policies yield the same results as the TPP scenarios (Table 2) and therefore are not included.

[b] Average annual change estimated from the following 2015 figures: 142.4 million cwt of production; 86.9 million cwt of consumption; 66.4 million cwt of net exports.

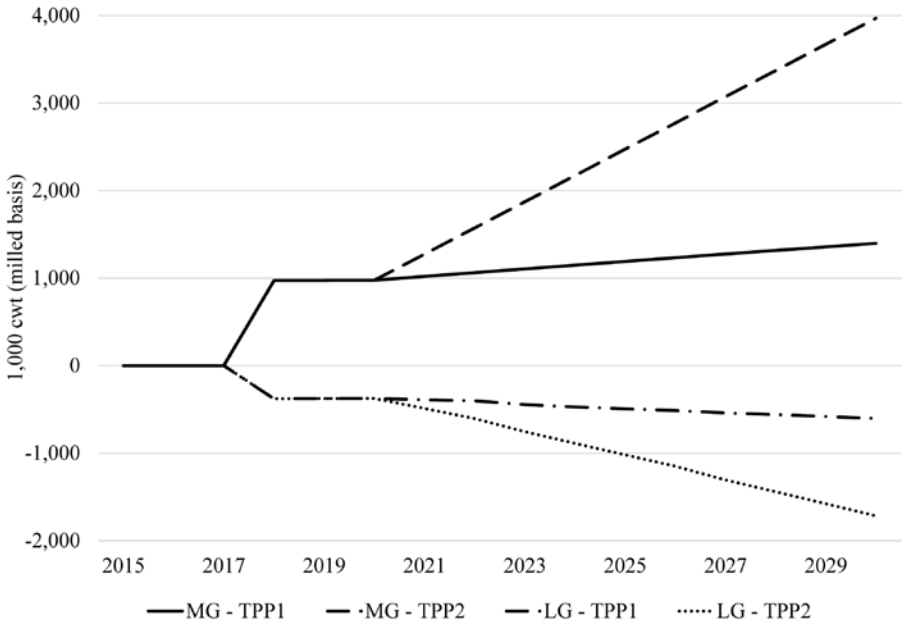

Fig. 1. Change in U.S. rice production by type as a result of the Trans-Pacific Partnership (TPP). TPP1: this scenario assumes the TPP Agreement is implemented as negotiated starting in 2017. TPP2: this scenario assumes the TPP Agreement is implemented as negotiated starting in 2017 by all countries, except that Japan grants a 4.4 million cwt (200 tmt) TRQ to the U.S. as follows: 1.1 million cwt (50 tmt) from year 1 to 3, and annual increases of 0.33 million cwt (15 tmt) up to 4.4 million cwt (200 tmt) by year 2029. This scenario approximates the initial U.S. negotiation request of Japan rice market access. MG: medium- and short-grain rice. LG: long-grain rice.

Rice Enterprise Budgets and Production Economic Analysis

W.A. Flanders[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 the 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.

INTRODUCTION

Technologies are continually changing for rice production. Simultaneously, volatile commodity prices and input prices present challenges for producers to maintain profitability. Producers need a 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 costs information for their specific farms.

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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, 2015). Labor costs in crop enterprise budgets represent time devoted to specified field activities.

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 November 2015. Representative prices for machinery and equipment are based on contacts with Arkansas dealers, industry list prices, and reference sources (Deere and Company, 2015; MSU, 2015). Revenue in crop enterprise budgets is the product of expected yields from following Extension practices under optimal growing conditions and projected commodity prices.

RESULTS AND DISCUSSION

The University of Arkansas System Division of Agriculture Department of Agricultural Economics and Agribusiness (AEAB) develops annual crop enterprise budgets to assist Arkansas producers and other agricultural stakeholders in evaluating expected costs and returns for the upcoming field crop production year. Production methods analyzed represent typical field activities as determined by consultations with farmers, county agents, and information from Crop Research Verification Program Coordinators in the Department of Crop, Soil, and Environmental Sciences. Actual production practices vary greatly among individual farms due to management preferences and between production years due to climactic conditions. Analyses are for generalized circumstances with a focus on consistent and coordinated application of budget methods for all field crops. This approach results in meaningful costs and returns comparisons for decision making related to acreage allocations among field crops. Results should be regarded only as a guide and a basis for individual farmers developing budgets for their production practices, soil types, and other unique circumstances.

Table 1 presents a summary of 2016 costs and returns for Arkansas dry-seeded, delayed-flood conventional rice. Costs are presented on a per acre basis and with an assumed 1000 acres. Program flexibility allows users to change total acres, as well as other variables to represent unique farm situations. Returns to total specified expenses are $330.51/acre. The budget program includes similar capabilities for Clearfield pureline, hybrid, and Clearfield hybrid cultivars, as well as water-seeded rice production.

Crop insurance information in Table 1 associates input costs with alternative coverage levels for insurance. For example, with an actual production history (APH) yield of 162.0 bu/acre and an assumed projected price of $5.50/bu, input costs could be insured at selected coverage levels greater than 42%. Production expenses represent what is commonly termed as "out-of-pocket costs," and could be insured at coverage levels greater than 47%. Total specified expenses could be insured at coverage levels of 74%.

SIGNIFICANCE OF FINDINGS

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.

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Table 1. Summary of 2016 revenue and expenses, conventional rice, per acre and 1000 acres.

Summary of revenue and expenses			Crop insurance information	
Revenue	**Per acre**	**Farm**		**Per acre**
Acres	1	1000		
Yield (bu)	180.0	180,000	APH[a] Yield	162.0
Price ($/bu)	5.50	5.50	Projected price	5.50
Grower share	100%	100%		
Total crop revenue	**990.00**	**990,000**	**Revenue**	**891.00**
Expenses			**Percent of revenue**	
Seed	33.84	33,840		4%
Fertilizers and nutrients	107.78	107,777		12%
Chemicals	99.53	99,531		11%
Custom applications	44.10	44,100		5%
Diesel fuel, field activities	14.71	14,713		2%
Irrigation energy costs	67.32	67,324		8%
Other inputs	5.15	5150		1%
Input costs	**372.44**	**372,435**		**42%**
Fees	0.00	0		0%
Crop insurance	6.00	6000		1%
Repairs and maintenance, includes employee labor	25.02	25,016		3%
Labor, field activities	12.27	12,273		1%
Production expenses	**415.72**	**415,724**		**47%**
Interest	9.87	9873		1%
Post-harvest expenses	119.43	119,430		13%
Custom harvest	0.00	0		0%
Total operating expenses	**545.03**	**545,028**		
Returns to operating expenses	**444.97**	**444,972**		
Cash land rent	0.00	0		0%
Capital recovery and fixed costs	114.46	114,457		13%
Total specified expenses	**659.49**	**659,485**		
Returns to specified expenses	**330.51**	**330,515**		

[a] APH = actual production history.

Cost-Effective Use of Water? Factors Influencing the Use of Irrigation Technologies and Water Management Practices by Arkansas Producers

Q. Huang[1], K. Kovacs[1], and Y. Xu[1]

ABSTRACT

This study examines factors that influence the decisions of rice and soybean producers to use more efficient irrigation technology and/or Water Management Practices (WMPs). Data from the Farm and Ranch Irrigation Survey (FRIS) are used. Most producers rely on gravity irrigation, and about half also use one or more water management practices (WMPs) to improve existing gravity systems. Producers growing more diverse crops or those with smaller shares of land irrigated by groundwater are more likely to use WMPs. Sprinklers are more likely to be used on larger farms and by producers with less experience on farms. When facing the risk of more frequent droughts, producers tend to use WMPs combined with gravity system as a response, not sprinklers.

INTRODUCTION

Arkansas is the largest producer of rice in the nation. Its agriculture is heavily irrigated with irrigated acreage ranking fourth nationwide (Schaible and Aillery, 2012). More than 60% of the state's water supply comes from groundwater in the Mississippi River Valley alluvial aquifer (USGS, 2008). An annual gap in groundwater as large as 7 million acre-feet is projected for 2050 (ANRC, 2015). In the focus groups conducted by the authors in November 2014 with producers from east Arkansas, the decline in groundwater supply was ranked among the top concerns.

Switching to more efficient irrigation technologies such as center pivot has often been proposed as a solution to water shortage problems. Water management practices (WMPs) could also conserve water because many could improve the performance of existing irrigation systems (Schaible and Aillery, 2012). Without switching to more efficient irrigation technology, a rice producer can augment water supply by building a tailwater pit to capture and store irrigation runoff from flooded fields or rainfall and reuse it for future irrigation. The producer can further reduce water use by improving

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irrigation uniformity with practices such as laser leveling and alternate row irrigation. This study investigates what factors affect producers' use of irrigation technologies and/or WMPs.

PROCEDURES

The main data sets used are the Farm and Ranch Irrigation Survey (FRIS), arguably the most comprehensive data on irrigation, and Census of Agriculture collected by the U.S. Department of Agriculture. It is a set of repeated cross-sectional data. We used 1988, 1994, 1998, 2003, and 2008. County-level climate data such as daily precipitation and temperature are obtained from National Climatic Data Center (NCDC, 2014). All temperature and precipitation measures are calculated as the average of the previous 30 years and only within growing seasons. To measure soil quality, the average saturated hydraulic conductivity (K_{sat}) is extracted from the Soil Survey Geographic database (SSURGO).

Statistical methods, in particular regression analysis methods such as Logit regression and Multinomial Logit regression, are used to analyze the data. Since gravity irrigation is the dominant irrigation system in rice production, rice producers only decide on whether to use any WMPs. The FRIS survey only asked about WMPs used under gravity system. So we have grouped all WMPs together. The Logit model is used to estimate the choice of rice producers: $\Pr(y_i = 1) = \exp(\mathbf{X\beta})/[1 + \exp(\mathbf{X\beta})]$, where y_i is a dummy variable that equals 1 if producer i uses one or more WMPs. The objective is to estimate the vector of parameters β that link X, which contains a set of relevant factors, to y_i. Soybean producers face one of three choices: gravity irrigation without WMPs, gravity irrigation with WMPs, and sprinkler irrigation. Their choices are estimated using the method of Multinomial Logit: $\Pr(y_i = j) = \exp(\mathbf{X\eta}_j)/\Sigma_l \exp(\mathbf{X\eta}_l)$, where j and l are both indices for the choices and $\boldsymbol{\eta}$ is the vector of parameters to be estimated.

RESULTS AND DISCUSSION

In Arkansas, the main irrigation method for all major crops is still gravity irrigation, which includes both furrow and flood irrigation. In 2008, 96.5% of rice acreage was under gravity system (Table 1). For all other major crops, more than 69% of irrigated acres use gravity irrigation. Producers that utilize sprinklers are still in the minority. Within sprinkler system, center pivot is the dominant technology. The percent of irrigated area using center pivots ranged from 1.6% for rice to 33.1% for cotton. About half of the producers also use one or more WMPs to improve existing gravity systems. Laser leveling and tailwater pit are the most commonly used practices (Table 2). Among the farms with gravity irrigation systems, 24.4% used laser leveling in 2008 and 24.0% had tailwater pits on farm. Other popular WMPs include alternative row irrigations (15.0%) and restricting runoff by diking the end of field (13.9%).

Farm size has a positive and statistically significant effect on the probability of observing sprinkler systems among soybean producers (Table 3). Given the require-

ment of large capital investments, larger farms are more likely to enjoy economies of scale. They are also more likely to have access to more credit for capital investment. It usually requires more labor to irrigate larger farms, which may also push the switch to sprinkler irrigation which is less labor intensive. Experience on farm has a negative and statistically significant impact on the probability of using sprinklers, probably because sprinklers require knowledge of new irrigation techniques. In contrast, since most WMPs such as laser leveling and tailwater pits involve structural change to the farm fields, knowledge of the farm, which increases with years of experience on farm, facilitates the adoption of WMPs. So more experienced producers may prefer WMPs over sprinkler irrigation. Farms with more diverse crop mixes tend to move away from gravity only systems or sprinkler systems to the combination of gravity and WMPs. Crop diversity is measured by the number of crop categories produced on a farm (e.g., grain crops, cash crops, fruits and vegetables, fodder crops). Producers with a more diverse crop mix usually grow cash crops such as cotton in addition to grain crops. It is likely those producers are using one or more WMPs to satisfy the irrigation demands of different crops both in terms of timing and quantities. For example, because different crops are grown in different times of the year, farms demand irrigation water for longer periods during the year. Water management practices such as tailwater pits can meet this demand by increasing water stored on farm.

The cost of water has a positive and significant effect on the likelihood of using WMPs among soybean producers, but not among rice producers (Table 3). The cost of water does not seem to affect the decision to use sprinkler irrigation. This is different from the positive relationship found in most previous studies (e.g., Caswell and Zilberman, 1986; Negri and Brooks, 1990). The small or insignificant effect in our study may be because the estimation is done conditional on crop choice. It may also because Arkansas soybean producers have chosen to use WMPs as the response to the higher cost of water. Greater reliance on groundwater increases the likelihood of using gravity irrigation but discourages the use of WMPs. Strong reliance on groundwater suggests this source of water is abundant. Groundwater is a preferred source of water because the quantity of groundwater varies much less seasonally than surface water. A greater reliance on groundwater, as measured by percentage of acres with groundwater irrigation, reduces the need for WMPs such as tailwater pits when water is scarce.

None of the temperature or precipitation related factors seem to affect a producers' decision to use WMPs (Table 3). Since rice is almost 100% irrigated, its growth may be much less sensitive to climatic factors. Among soybean producers, the percent of years with severe droughts, constructed using the Palmer Drought Severity Index (Palmer, 1965; NIDIS, 2014), has a negative and statistically significant impact on the likelihood of choosing the sprinkler system. Both sprinklers and WMPs can improve control over irrigation applications. Arkansas soybean producers have chosen WMPs as their responses to more frequent droughts. In contrast, producers in other regions such as California have relied on sprinkler irrigation (Zilberman et al., 1995). This may be because Arkansas crop production is less capital intensive than in other states such as California. It may also be because policy makers in Arkansas have been promoting

WMPs such as tailwater pits as a way to increase surface water use (ANRC, 2015). The policy nudge toward surface water use may also reduce the popularity of sprinklers since modern irrigation technologies are more likely to be used on fields with groundwater supplies because groundwater is usually delivered at higher pressure (Caswell and Zilberman, 1986).

SIGNIFICANCE OF FINDINGS

Conditional on crop choice, cost of water does not seem to have a large impact on the use of sprinklers. Increasing water price is not an effective tool to promote the use of sprinklers in Arkansas. Farm experience does not seem to increase the chance of using sprinklers. More Extension efforts should be made to reduce producers' learning curve of practices that require new knowledge. Examples include modern irrigation technologies, such as WMPs that can improve gravity systems such as computerized hole selection and sophisticated irrigation scheduling practices like soil or plant moisture-sensing devices and computer simulation model.

Although both more efficient irrigation technologies and WMPs can alleviate climate risk, WMPs are used to mitigate the impact of more frequent droughts. Given Arkansas's recent drought experience in 2010/11 and the expectation of higher frequencies of droughts in the future (Arkansas Governor's Commission on Global Warming, 2008), it is important for agricultural extension specialists to provide producers with climate information to manage farm risk and help them with both modern irrigation technology and WMPs as tools to deal with a more volatile climate and extreme events such as drought stress or frost. Since most modern irrigation technologies are capital intensive and most WMPs require more labor, the large farms tend to prefer irrigation technologies and the smaller farms tend toward WMPs.

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Table 1. Percent of irrigated area under each irrigation system in 2008.

	Sprinkler system		Gravity system
	Center pivot	Other sprinkler system	
	(%)		
Corn	28.3	2.4	69.3
Soybean	20.3	3.1	76.6
Rice	1.6	1.9	96.5
Cotton	33.1	0.8	66.1

Table 2. Percent of farms with gravity systems that have used a practice in 2008.

System	Farms
	(%)
Laser leveling	24.4
Tailwater pits	24.0
Alternate row irrigations	15.0
Restricting runoff by diking end of field	13.9
Reducing irrigation set times or number of irrigations	4.57
Shorten furrow length	2.83
Surge flow or cablegation irrigation	0.65

Table 3. Factors that influence the choice of irrigation system and water management practices (WMPs).

	Rice[a]	Soybean[b]		
	Gravity and WMP	Gravity	Gravity and WMP	Sprinkler
Experience on farm	0.00172	0.000863	0.000667	-0.00153*
	(0.00557)	(0.000862)	(0.000809)	(0.000645)
Farm size in acre	0.00123	-0.300	-0.179	0.479*
	(0.00146)	(0.337)	(0.331)	(0.226)
Crop diversity	0.36580***	-0.0437*	0.0738***	-0.0302
	(0.12672)	(0.0218)	(0.0195)	(0.0185)
% of land that is rented in	-0.22969	0.0528	-0.00817	-0.0446
	(0.19132)	(0.0351)	(0.0328)	(0.0247)
Cost of water in $/acre-foot	-0.00019	-0.0128	0.0247**	-0.0118
	(0.00174)	(0.00975)	(0.00892)	(0.00649)
% of acres irrigated by groundwater	-1.13546***	0.271***	-0.312***	0.0409
	(0.35458)	(0.0478)	(0.0422)	(0.0351)
Soil permeability	-0.00545	0.000302	-0.000890	0.000588
*Farm size	(0.00356)	(0.00120)	(0.00112)	(0.000698)
Mean daily temperature	-0.01923	0.00240	0.00452	-0.00692
*Farm size[c]	(0.02701)	(0.00550)	(0.00546)	(0.00381)
Total precipitation	0.00718	0.00449	-0.00732	0.00282
*Farm size[c]	(0.03083)	(0.00597)	(0.00600)	(0.00391)
% of years with severe droughts	0.02304	-0.0847	0.752***	-0.668***
*Farm size[c]	(2.01045)	(0.245)	(0.225)	(0.192)
Share of days with intensive precipitation	0.31185	-0.00389	-0.196	0.200
*Farm size[c]	(0.74268)	(0.209)	(0.204)	(0.123)
Year dummies	YES		YES	
County dummies	NO		NO	
Observations	1,298		1,704	
Observations	1,298		1,704	

Standard errors not reported for the sake of brevity; *significant at 10%; **significant at 5%, ***significant at 1%.

[a] The average marginal effects estimated with the Logit regression are reported for rice.

[b] The average marginal effects estimated with the Multinomial Logit regression are reported for soybean.

[c] All temperature and precipitation measures are calculated as the average of previous 30 years and only within growing seasons.

Economic Simulation Analysis of Margin Protection Crop Insurance in Arkansas Rice Production

R.U. Mane[1] and K.B. Watkins[1]

ABSTRACT

Rice is an irrigated crop, and irrigated crops are more insulated against yield risk than non-irrigated crops. However, rice is largely dependent on energy related inputs like fuel and fertilizer and suffers from systemic risks caused by increasing energy related input costs. The USDA Risk Management Agency (RMA) is making available a new insurance product to rice producers in 2016 called Margin Protection (MP). Margin Protection provides coverage against an unexpected decrease in operating margin resulting from increased input costs. This study used simulation to evaluate the likelihood of indemnities generated by MP at various coverage levels ranging from 70% to 90% for three major rice counties in Arkansas. The likelihood of receiving indemnities under MP was small for 70% and 75% coverage levels. Indemnity probabilities were 0.8%, 5.2%, and 18% for Arkansas County at MP coverage levels of 80%, 85%, and 95%, respectively. Indemnity probabilities for Poinsett and Desha Counties were higher at the 80%, 85%, and 90% coverage levels (6%, 18.8%, and 31.9%, respectively, for Poinsett; 6.6%, 16.8%, and 34.6%, respectively, for Desha). The higher indemnity probabilities in Poinsett and Desha may be due to higher yield variability for those counties.

INTRODUCTION

Rice production is an expensive enterprise when compared to production of other row crops such as corn, soybean, grain sorghum, and wheat. According to Arkansas Crop Enterprise Budgets reports (2011 - 2015) the net operating cost per acre for rice is the highest ($641.08) when compared to other row crops like cotton ($523.90), corn ($571.80), sorghum ($317.12), and soybean ($313.74). However, rice is more profitable ($436.40) when we compare the per acre returns to operating expenses with other crops like cotton ($378.50), corn ($397.80), soybean ($376.66), and sorghum ($211.10). A typical farm involved in rice production requires physical assets (e.g., equipment, irrigation infrastructure) worth $2.5 million; whereas a soybean farm would require assets less than a $1 million (Fahr, 2015). Therefore, it is important for the rice

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producers to be profitable or have certain margins over their production costs for their economic sustainability.

In May 2015, the Risk Management Agency (RMA) of the U.S Department of Agriculture (USDA-RMA; 2015a,b) announced a new crop insurance product called Margin Protection (MP) would be available for selected crops in selected counties. In Arkansas, MP Policies are available for 26 rice-growing counties (Arkansas, Ashley, Chicot, Clay, Craighead, Crittenden, Cross, Desha, Drew, Greene, Independence, Jackson, Jefferson, Lawrence, Lee, Lincoln, Lonoke, Mississippi, Monroe, Phillips, Poinsett, Prairie, Randolph, Saint Francis, White, Woodruff) starting in the 2016 crop year (USDA-RMA, 2015a). Margin Protection is an area-based product, using county-level estimates of average revenue and input costs to establish the amount of coverage and indemnity payments. The objective of MP is to provide coverage against an unexpected decrease in operating margin (revenue less input costs). Allowed MP inputs subject to price change in rice production include diesel, urea, DAP (diammonium phosphate), potash, and operating interest. Margin Protection can be purchased as a stand-alone product or in combination with other crop insurance products such as Revenue Protection (RP) and Yield Protection (YP). Coverage levels for MP range from 70% to 90% of expected margins and are purchased in 5% increments (USDA-FCIC, 2015).

PROCEDURES

The procedure to estimate or calculate indemnities for rice MP is based on guidelines set forth by the USDA's Federal Crop Insurance Corporation (FCIC) *Margin Protection Plan of Insurance Standards Handbook* (USDA-FCIC, 2015). The indemnity for rice MP Insurance (MPI) is calculated as $MPI = TM - HM$, where TM equals the trigger margin and HM is the harvest margin. The TM is calculated as $TM = EM \times CL$, where EM is the expected margin and CL is the percent of EM covered by MP (70%, 75%, 80%, 85%, and 90%). The EM is calculated as $EM = ER - EC$, where ER is Expected Revenue (projected rice price × expected county rice yield) and EC = Expected Costs, which is the sum of variable inputs (allowable input quantities of diesel, urea, diammonium phosphate (DAP) and potash multiplied by their respective projected prices), plus fixed input costs (for maintenance, chemicals, and application), plus projected interest applied to variable and fixed input costs for a 6 month period.

The Harvest Margin (HM) is calculated as $HM = HR - HC$, where HR = Harvest Revenue and HC = Harvest Costs. Both HR and HC are calculated the same as ER and EC above with the exception that harvest prices are used in place of projected prices, a harvest interest rate is used instead of a projected interest rate, and final county yield is used in place of the expected county yield. Finally, net indemnities are calculated as $NMPI = MPI - PREMIUM$, where $NMPI$ is Net MP Indemnity, and $PREMIUM$ is the producer's MP subsidized premium for the coverage level purchased. Margin protection premiums by county and coverage level for this study were obtained from the MP price discovery prompt of the "Margin Protection for Corn, Rice, Soybeans and Wheat" website (USDA-RMA 2015b).

Allowable input quantities and fixed input costs for maintenance, chemicals, and application are obtained from Watts and Associates, Inc. on behalf of the RMA (Watts and Associates, 2015). Expected county yields for each county (Arkansas, Poinsett, and Desha) were obtained from the MP price discovery prompt of the USDA-RMA *Margin Protection for Corn, Rice, Soybeans and Wheat* website (USDA-RMA 2015b). Final county yields and projected and harvest prices for rice, urea, DAP, potash, and interest were simulated as empirical distributions using SIMETAR (SIMulation of Econometrics To Analyze Risk; Richardson et al., 2008). All price simulations were based on historical price data for the period 2006-2015, while all final county yield simulations were based on rice county yield data for Arkansas, Poinsett, and Desha Counties for the period 2005-2014. Five hundred iterations were simulated for each price and county rice yield. For more information about the price and yield data used in the simulations, see Mane and Watkins (2016).

RESULTS AND DISCUSSION

Margin Protection Premiums by County and Coverage Level

Rice MP premiums are presented by county and coverage level in Table 1. Arkansas County has the lowest premiums followed by Poinsett and Desha Counties. The premium data reported in Table 1 are total premiums and producer premiums (total premiums less producer subsidies). The amount of premium paid by the producer increases and the producer subsidy decreases as coverage levels increase. In general, premiums are based on yield performance of counties. Based on National Agricultural Statistics Service historic data, Arkansas County has the highest yield on average for the last 10 years when compared to Poinsett and Desha Counties (USDA-NASS, 2016). Likewise, Poinsett County has higher yields on average for 6 years when compared with Desha County. The premium difference is less between Poinsett and Desha Counties at different coverage levels when compared to Arkansas County. Based on analysis by Makki and Somwaru (2001) of RMA data, it was concluded that producers' choice of an insurance product is based on cost of premium, subsidy associated with the premium, and level of coverage. We can assume the preference to purchase a MP policy will be based on the same parameters as listed above.

Simulated Rice Margin Protection Indemnity Statistics by County and Coverage Level

Simulated rice MP indemnities are presented by county and coverage level in Table 2. Average simulated indemnities are largest for the higher coverage levels (80%, 85%, and 90%). However, both minimum and median indemnities for all coverage levels and counties equal zero, implying the likelihood of receiving an indemnity for MP as well as for other traditional insurance products such and YP and MP is small for any given year. Probabilities of receiving and indemnity over 500 simulated outcomes are presented in the right column of Table 2. The probability of receiving an indemnity increases as coverage levels increase from 70% to 90%.

Probabilities of receiving an indemnity vary by county. Indemnity probabilities are lowest for Arkansas County (Table 2). The probability of receiving an MP indemnity in Arkansas County at 80%, 85%, and 90% coverage levels is 0.8%, 5.2%, and 18% respectively. There is no indemnity for MP at 70% and 75% coverage levels for Arkansas County. Poinsett and Desha counties have a probability of approximately 1% and 3% of receiving an indemnity at 70% and 75% coverage levels and have higher probabilities of receiving an indemnity than Arkansas County at the 80%, 85%, and 90% coverage levels. Based on the simulated results we can argue that MP indemnities are more likely to be triggered for higher coverage levels and are larger in magnitude for counties with relatively lower and more variable rice yields.

Simulated Rice Margin Protection Net Indemnity Statistics by County and Coverage Level

Simulated rice MP net indemnities are presented by county and coverage level in Table 3. The net indemnities on MP is the difference between total indemnity (Table 2) and the producer premium (Table 1) at each coverage level. In most instances, net indemnities are negative on average, reflecting the fact that in most years producers will receive no indemnity and will incur a premium cost (Table 3). This is also borne out by the fact that both the minimum and median net indemnities reported for all coverage levels equal the premiums reported in Table 1 by coverage level. However, average net indemnities are positive for Poinsett and Desha Counties at the 90% coverage level, implying that positive net indemnities occur more frequently at the highest coverage level for these two counties (Table 3).

The likelihood of receiving positive net indemnities is greater at all coverage levels for Poinsett and Desha Counties relative to Arkansas County (Table 3). Higher net positive indemnities in Poinsett and Desha Counties reflects higher yield variability and lower yields in these counties which are most likely to trigger an indemnity. On the contrary, Arkansas County has lower relative rice yield variability and higher rice yields and is less likely to trigger indemnities relative to the other two counties.

Input and Output Factors Affecting the Likelihood of Triggering Rice Margin Protection Indemnities

This section describes some insight obtained by looking at individual simulated iterations with triggered indemnities. We found in most instances that escalating fertilizer prices (urea, DAP, and Potash) coupled with low yields and low harvested prices increased the likelihood of triggering an indemnity for MP, particularly at the 85% and 90% coverage levels for all selected counties. It would be difficult to rank which of the following factors; price of urea, DAP, potash, Yield of rice or Harvest Price of rice is the most important factor contributing to indemnity payment for margin protection policy. It is interesting to note that upward movement in the price of diesel as an input by itself or in combination with other inputs like urea, DAP or potash would least likely

trigger an indemnity payment. Almost all indemnity payments on the input side were associated with higher input prices for urea, DAP, and potash. Likewise, lower yields and lower harvest prices can equally contribute to trigger an indemnity.

SIGNIFICANCE OF FINDINGS

Margin Protection is an insurance product instituted to protect against unexpected decreases in operating margin resulting from unexpected increases in input prices, reductions in output prices, and lower than expected county yields. Based on our simulated results, MP is more effective in addressing risk at higher coverage levels (80%, 85%, and 90%) when prices of urea, DAP, and potash are higher and yield and harvest prices are lower. We also found the likelihood of indemnities increases for counties with relatively more yield variability and/or lower yields.

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Table 1. Rice Margin Protection premiums at different coverage levels for selected counties in Arkansas.[a]

	Coverage levels				
County and premium type	**70%**	**75%**	**80%**	**85%**	**90%**
	($/acre)				
Arkansas					
Total premium	2.16	4.58	8.77	15.37	25.22
Producer premium	0.89	2.06	3.95	7.84	14.12
Poinsett					
Total premium	2.92	5.69	10.07	16.82	26.21
Producer premium	1.20	2.56	4.53	8.58	14.68
Desha					
Total premium	3.51	6.67	11.61	18.90	28.90
Producer premium	1.44	3.00	5.22	9.64	16.18

[a] Source: Risk Management Agency (RMA) MP Actuarial Data as of 8 December 2015. (USDA-RMA. 2015b).

Table 2. Simulated indemnities by coverage level summary statistics ($/acre), for Arkansas, Poinsett, and Desha Counties in Arkansas.

Coverage level	Mean[a]	SD[b]	CV[c]	Minimum	Median	Maximum	Indemnity
(%)	($/acre)						(%)
Arkansas County							
70	0.00	0.00	---	0.00	0.00	0.00	0.0
75	0.00	0.00	---	0.00	0.00	0.00	0.0
80	0.10	1.28	13.16	0.00	0.00	23.96	0.8
85	0.79	4.55	5.79	0.00	0.00	57.44	5.2
90	3.86	11.14	2.88	0.00	0.00	90.92	18.0
Poinsett County							
70	0.16	2.33	14.43	0.00	0.00	41.38	0.8
75	0.54	3.97	7.41	0.00	0.00	55.88	3.0
80	1.58	7.54	4.76	0.00	0.00	70.38	6.0
85	4.39	13.20	3.00	0.00	0.00	84.88	18.8
90	10.85	21.40	1.97	0.00	0.00	115.81	31.6
Desha County							
70	0.09	1.22	14.32	0.00	0.00	23.22	0.6
75	0.44	3.14	7.12	0.00	0.00	37.86	3.2
80	1.45	6.90	4.76	0.00	0.00	67.59	6.6
85	4.37	12.91	2.96	0.00	0.00	98.17	16.8
90	11.46	21.79	1.90	0.00	0.00	128.75	34.6

[a] Indemnity statistics are based on 500 simulated iterations.
[b] SD = Standard deviation.
[c] CV = Coefficient of variation, a unitless measure of relative risk equal to the ratio of the standard deviation (SD) divided by the mean multiplied by 100.

Table 3. Simulated net indemnities by coverage level summary statistics ($/acre), for Arkansas, Poinsett, and Desha counties in Arkansas.

Coverage level	Mean[a]	SD[b]	CV[c]	Minimum	Median	Maximum	Positive net indemnity
(%)	($/acre)						(%)
Arkansas County							
70	-0.89	0.00	0.00	-0.89	-0.89	-0.89	0.00
75	-2.06	0.00	0.00	-2.06	-2.06	-2.06	0.00
80	-3.85	1.28	-0.33	-3.95	-3.95	20.01	0.60
85	-7.05	4.55	-0.65	-7.84	-7.84	49.60	3.20
90	-10.26	11.14	-1.09	-14.12	-14.12	76.80	9.40
Poinsett County							
70	-1.04	2.33	-2.25	-1.20	-1.20	40.18	0.80
75	-1.98	4.16	-2.10	-2.56	-2.56	54.68	3.00
80	-2.75	8.21	-2.99	-4.53	-4.53	69.18	6.00
85	-2.80	15.34	-5.48	-8.58	-8.58	83.68	17.80
90	0.46	26.41	57.28	-14.68	-14.68	114.61	31.20
Desha County							
70	-1.35	1.22	-0.90	-1.44	-1.44	21.78	0.60
75	-2.51	3.36	-1.34	-3.00	-3.00	36.42	3.00
80	-3.52	7.67	-2.18	-5.22	-5.22	66.15	6.40
85	-3.89	15.36	-3.94	-9.64	-9.64	96.73	16.20
90	0.38	27.30	71.76	-16.18	-16.18	127.31	33.20

[a] Indemnity statistics are based on 500 simulated iterations.
[b] SD = Standard deviation.
[c] CV = Coefficient of variation, a unitless measure of relative risk equal to the ratio of the standard deviation (SD) divided by the mean multiplied by 100.

World and U.S. Rice Outlook: Deterministic and Stochastic Baseline Projections, 2015-2025

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ABSTRACT

Global rice trade and prices are projected to grow steadily over the next decade as exports expand in Cambodia, Thailand, Myanmar, and Vietnam, and imports continue to grow strongly in the Western African countries and the Middle East. The U.S remains a top five rice exporter in the world with exports accounting for nearly half of total U.S. rice output. Growth in global rice production comes mainly from yield improvements as limited area for expansion remains constrained. Abundant rice supplies are projected due to current surpluses, productivity growth using new technologies, and increases in production subsidies in many countries. Population remains the driver of global consumption growth as per capita use declines slightly. Inherent risks in the global rice economy due to the uncertainties of weather, domestic policies, and political developments, generate unexpected prices and trade. Hence historic statistical distributions of yields are used for stochastic analysis, generating probable upper and lower bounds (confidence intervals) of future distribution of prices and trade.

INTRODUCTION

This document contains baseline rice projections from the Arkansas Global Rice Economics Program (AGREP) under the University of Arkansas System Division of Agriculture Department of Agricultural Economics and Agribusiness, Fayetteville. The purpose of this outlook is not to predict, but to present the current state and the expected directions of the rice economies in the world over the next decade by assessing potential supply and demand paths as well as the degree of variability on some of the key variables.

Until 2014, the global rice market was dominated by Thailand's controversial and costly paddy pledging program (PPP), a politically motivated price-floor support policy for Thai farmers (Wailes and Chavez, 2013). With the end of this costly program, Thailand has re-captured its leadership position in global rice trade (USDA-FAS, 2014). Thai rice is now priced competitively and is used in this study as the world long-grain reference price.

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PROCEDURES

The deterministic and stochastic 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 that covers 61 rice-producing and -consuming countries/regions developed and maintained by the AGREP.

Most of the details and the theoretical structure of the Arkansas Global Rice Model, with the exception of the newly added countries, can be found in online documentation by Wailes and Chavez (2011). Historical rice data are sourced from USDA-FAS (2016) and USDA-ERS (2016); and the macroeconomic data are from IHS Global Insight through Food and Agricultural Policy Research Institute-Missouri (FAPRI-MU, 2016). The baseline projections are grounded in a series of assumptions as of January 2016 about the general global economy, agricultural policies, weather, and technological change. The basic assumptions include the following: a continuation of existing policies, IHS (IHS, Inc.) macroeconomic projections, no new World Trade Organization (WTO) trade reforms, and average weather conditions. In light of the historical volatility of the global rice economy, a stochastic analysis is included in this report to provide a better understanding of the probable distribution of future price and trade outcomes.

RESULTS AND DISCUSSION

Deterministic Analysis

Over the next decade, growth in global domestic use is projected to exceed domestic supply causing increasing total rice trade and steadily increasing nominal long-grain international prices. Major rice-deficit countries continue to import as domestic production falls short of domestic demand despite subsidies and expressed desires to achieve self-sufficiency. The average long-grain rice international reference price (Thai 100%B) increases from $405/metric ton (mt) (2013-2015 average) to $545/mt in 2025 (Wailes and Chavez, 2016).[2] Over the same period, international medium-grain rice prices are projected to remain at a relatively higher level, ranging from $828-845/mt (Table 1), as segmentation remains in trade flows and prices of long- and medium-grain rice markets.

While Thai prices and other exporter prices have recently converged, Western Hemisphere (U.S. and Mercosur) prices remain substantially higher—with margins to Asian prices reaching as high as nearly $200/mt in September 2015, an unsustainable level. Margins have narrowed since then and are projected to further decline to a more historically consistent level of about $65/mt by 2025, the end of the projection period (Table 1). Rigidity in moving the margin narrower is based on quality differences and negotiated tariff preferences for U.S. rice in bilateral and regional trade agreements.

Over the projection period, India and the People's Republic of China (PRC) will continue to account for the bulk of the global rice economy. In combination, these two

[2] Although complete baseline projections for supply and demand variables are generated for all 61 countries/regions covered by the AGRM, only selected variables are included in this report due to space consideration.

countries are projected to account for 35.3% of the world population from 2015-2025. Over the same period, they will have an average combined share of 45.3% of world rice area harvested, 51.2% of total milled rice production, 50.2% of total rice consumption, and 66.2% of world rice ending stocks.

Rice output is projected to expand over the next decade, driven by the use of higher-yielding varieties and hybrids and other improved production technologies—in line with more subsidies for self-sufficiency programs of major consuming countries. World production is projected to expand by 50.2 million metric tons (mmt) over the next decade, equivalent to a growth of 1.0% per year; and reaching a total global output of 525.8 mmt in 2025 with 90% of the growth from yield improvement and 10% from increases in area harvested (Table 2). By volume, 34.1% of the expected output growth will come from India; 40.9% from the seven countries of Bangladesh, Indonesia, Thailand, Cambodia, Myanmar, Philippines, and Vietnam combined; and 9.0% from the 15-member Economic Community of West African States (ECOWAS). Rice output of the China however, declines by a total of 1.2 mmt, and those of Japan and South Korea decline by a combined 1.1 mmt over the same period. Total U.S. rice production, on the other hand, is projected to increase by a total of about 1.1 mmt (or 36.6 mil. cwt) over the same period, equivalent to 1.6% annual growth—with annual growth of 1.0% in area harvested and 0.6% annual yield growth (Table 3).

Factors driving rice consumption are income, population, and other demographic variables. Rising incomes dampen rice demand in some Asian countries where rice is considered an inferior good. These countries include Japan, Taiwan, PRC, Vietnam, and Thailand. Demographic trends also weaken rice demand as aging populations and increasing health consciousness shift preferences away from carbohydrates and towards protein-based diets.

Over the baseline, global rice consumption is projected to increase by 43.6 mmt reaching 524.9 mmt in 2025—a growth of 0.8% per year, with population growth of 1.1% per year projected to be offset partly by a 0.3% decline in average world rice per capita use (Table 2).

About 31.3% of the total growth is accounted for by India; 24.6% by the four countries of Bangladesh, Indonesia, the Philippines, and Myanmar combined; and 17.8% by ECOWAS. United States rice total consumption increases by nearly 280 thousand metric tons (tmt) or 9.4 million hundred weight (cwt) over the same period, reaching 4.3 mmt (135.0 million cwt) in 2025 or an annual growth of 0.7%; which is solely coming from population growth as per capita use declines slightly. Global rice stocks have tightened recently, with stocks-to-use at 18.4% in 2015, the lowest on record over the last 30 years. The reason for this situation is that consumption exceeded production over the last 3 years, coupled with the disposal of excess rice stockpiles by India and Thailand amounting to nearly 22 mmt from 2013-2015. Global stocks-to-use is projected to decline further to 16.0% in 2019 before recovering gradually to 17.6% by the end of the projection period, which to a certain extent, provides underlying support to the projected steady increase in international prices.

Total global rice trade expands 1.4%/year, reaching 48 mmt in 2025 up from 42 mmt in 2015 (Table 1). On the exporters' side, the significant investment in production

and processing capacity in Mekong Delta in Vietnam, Cambodia and Myanmar bodes well for these countries' increasing their role as major rice suppliers in the coming years. As low-cost producers, these countries are well-poised geographically to supply the steadily growing China market. The productivity gains from hybrids and Global Rice Science Partnership (GRiSP) research are expected to have positive impacts on Asian and African rice economies. As a result of Thailand's termination of its costly, unpopular, and controversial PPP, the country has resumed its leadership position in global trade since 2015 and is projected to maintain a strong presence in the international rice market over the next decade—given its good infrastructural resources and concerted focus on developing and maintaining a strong presence in the branded high quality rice market. Based on USDA-FAS data (2016), the country has liquidated about 7.6 mmt of its excess stocks over the last 3 years. For the U.S., total rice exports expand by 622 tmt or 20.3 million cwt over the next decade, reaching 3.8 mmt (or 119 million cwt) in 2025; and total imports grow by 64 tmt (or 2.0 million cwt), reaching 828 tmt (or 26 million cwt) in 2025. For reference purposes, a detailed U.S. rice supply and use in English units is presented in Table 3. Cambodia's exports are projected to expand at 11.6%/year, reaching 2.9 mmt in 2025 as both area and yield growth cause production to exceed consumption consistently (Table 1). Myanmar's exports, on the other hand, are projected to expand from 1.8 mmt in 2015 to 2.9 mmt in 2025, supported by yield-based growth in production.

On the demand side, while China remains an important major rice importer over the next decade, its imports are relatively flat as it maintains a reasonable stock level. Nearly 72% of the growth in global imports will come from Africa, with the ECOWAS accounting for 79% of the growth in African imports. In general, expansion in imports is associated with a combination of lagging production relative to consumption and population growth.

Stochastic Analysis

The detailed results of the stochastic analyses for selected prices and trade are presented in Figs. 1 through 5. In order to show the direction and dispersion of the stochastic outcome distribution, four selected outcome items (stochastic average, 10th percentile, 90th percentile, and the coefficient of variation) for selected variables are presented. Intuitively, the gap between the two percentiles (10th and 90th) indicates volatility or risk. Widening indicates increased volatility and narrowing indicates decreased volatility. Another measure of dispersion used is the coefficient of variation (C.V.) which shows the extent of variability of data points in relation to the mean. Lower C.V. indicates more stability, i.e., less risk. The information projected in each one of the charts is similar in principle. Hence, for space consideration only one representative chart (Fig. 1) will be discussed—which can then be used as a basis to understanding the remaining charts. Figure 1 shows the long-grain rice international reference price. For 2016, while the deterministic mean price is $456/mt (Table 1), the stochastic distribution indicates that 10% of the time the average price will be higher than $569/mt and 10% of the time lower than $426/mt (Fig. 1). The computed C.V. for 2016 is 11.0%,

which declines steadily throughout the projection period, reaching 8.1% by 2025. This feature of the stochastic analysis provides an advantage as it indicates how the possible outcomes are distributed, thus providing a better understanding of the dynamics of the global rice market.

SIGNIFICANCE OF FINDINGS

Understanding the market and policy forces that drive the global rice market are beneficial for Arkansas rice stakeholders. This is especially true because Arkansas is the top rice-producing state in the U.S. accounting for 45% of the country's rice output; and nearly half of Arkansas annual rice crop is exported. Market prices received by Arkansas rice producers are primarily determined by the factors that affect international trade. These include changes in rice production and consumption patterns, the economics of alternative crops, domestic and international rice trade policies, as well as the general macroeconomic environment in which global rice trade is transacted. While the results presented in this outlook are not predictions, they can be considered as a synthesis of the impacts of these factors, and serve to indicate what could happen over the next decade—and could serve as baseline reference for further analysis. The estimates are intended for use by government agencies and officials, farmers, consumers, agribusinesses and other stakeholders who conduct medium- and long-term planning.

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Table 1. World rice total trade by country and international reference prices, 2014-2025.

Country	Units	14/15	15/16	16/17	17/18	18/19	19/20	20/21	21/22	22/23	23/24	24/25	25/26
	(mt)												
Exporters													
United States	(1000 mt)	3207	3273	3412	3490	3576	3655	3695	3714	3723	3734	3749	3783
Thailand	(1000 mt)	9200	10197	9482	9489	9551	9564	9604	9905	10405	10762	11295	11723
Pakistan	(1000 mt)	4000	4584	4125	4166	4212	4276	4250	4340	4314	4328	4273	4235
Myanmar	(1000 mt)	1750	1763	1741	1949	2045	2180	2251	2388	2495	2644	2748	2889
Vietnam	(1000 mt)	6500	7177	7006	6967	7114	7215	7455	7428	7389	7555	7539	7504
People's Republic of China	(1000 mt)	426	450	523	596	650	686	730	776	824	873	905	929
India	(1000 mt)	11871	8524	9132	8902	8666	8530	8579	8423	8322	8174	8142	8237
Cambodia	(1000 mt)	1100	798	1116	1374	1588	1819	2035	2203	2439	2627	2736	2894
Lao PDR	(1000 mt)	-125	-113	-33	25	54	71	107	125	175	219	264	274
Australia	(1000 mt)	370	97	221	329	420	484	525	549	562	567	571	573
Egypt	(1000 mt)	250	397	425	464	489	506	515	516	513	508	503	493
Turkey	(1000 mt)	27	27	27	27	27	27	27	27	27	27	27	27
European Union 28	(1000 mt)	272	329	329	330	332	334	333	333	333	333	333	333
Brazil	(1000 mt)	1000	886	902	929	906	912	916	911	913	913	913	913
Cote d'Ivoire	(1000 mt)	30	30	30	30	30	30	30	30	30	30	30	30
Senegal	(1000 mt)	10	10	10	10	10	10	10	10	10	10	10	10
Guinea	(1000 mt)	50	50	50	50	50	50	50	50	50	50	50	50
Tanzania	(1000 mt)	30	30	30	30	30	30	30	30	30	30	30	30
Japan	(1000 mt)	80	80	80	80	80	80	80	80	80	80	80	80
Argentina	(1000 mt)	400	514	538	539	540	540	538	540	540	540	541	544
Uruguay	(1000 mt)	800	948	897	940	965	990	1012	1025	1028	1037	1035	1034
Paraguay	(1000 mt)	410	517	553	580	607	634	661	680	709	737	767	795
Peru	(1000 mt)	20	68	75	80	83	87	88	90	91	92	93	94
ROW and Residual	(1000 mt)	1415	1296	1225	1184	1141	1128	1094	1073	1024	980	935	925
Total Exports	(1000 mt)	43093	41932	41895	42563	43165	43839	44614	45246	46027	46851	47568	48402

continued

Table 1. Continued.

Country	Units	14/15	15/16	16/17	17/18	18/19	19/20	20/21	21/22	22/23	23/24	24/25	25/26
	(mt)												
Importers													
United States	(1000 mt)	783	776	769	764	771	791	815	821	820	824	828	828
Thailand	(1000 mt)	300	400	333	344	359	346	350	352	349	350	350	350
Pakistan	(1000 mt)	30	35	32	32	33	33	33	33	33	33	33	33
Vietnam	(1000 mt)	400	400	400	400	400	400	400	400	400	400	400	400
People's Republic of China	(1000 mt)	4315	4712	4081	3982	3985	3984	3995	4013	4030	4051	4076	4097
China-Hong Kong	(1000 mt)	340	364	373	379	391	393	397	400	404	407	411	414
Egypt	(1000 mt)	34	25	25	25	25	25	25	25	25	25	25	25
Japan	(1000 mt)	650	682	682	682	682	682	682	682	682	682	682	682
Bangladesh	(1000 mt)	1224	646	784	695	790	873	817	798	817	848	879	957
Indonesia	(1000 mt)	1100	2066	2075	2109	2075	2019	1950	1942	1867	1759	1628	1525
Iraq	(1000 mt)	1100	1201	1395	1488	1562	1618	1681	1742	1795	1910	2009	2116
Iran	(1000 mt)	1400	1681	1640	1651	1729	1768	1847	1871	1918	1971	2066	2097
Malaysia	(1000 mt)	1000	1001	1062	1044	1060	1047	1045	1045	1049	1062	1076	1083
Philippines	(1000 mt)	1800	2077	1404	1602	1709	1819	1809	1713	1645	1670	1633	1618
Saudi Arabia	(1000 mt)	1460	1556	1511	1562	1593	1625	1660	1695	1731	1765	1799	1832
European Union 28	(1000 mt)	1703	1512	1520	1537	1555	1574	1597	1621	1639	1660	1680	1700
Singapore	(1000 mt)	300	303	307	313	315	316	319	320	322	323	324	325
Brunei Darussalam	(1000 mt)	40	41	41	43	44	45	46	47	48	50	50	52
Turkey	(1000 mt)	317	291	288	263	248	239	231	231	236	239	236	234
South Korea	(1000 mt)	450	471	409	409	409	409	409	409	409	409	409	409
Taiwan	(1000 mt)	125	126	126	126	126	126	126	126	126	126	126	126
Australia	(1000 mt)	150	181	171	168	165	162	159	156	153	150	147	144
Brazil	(1000 mt)	450	742	812	807	779	679	640	500	482	449	444	412
Mexico	(1000 mt)	698	720	762	767	780	794	813	822	834	847	862	873
Canada	(1000 mt)	350	361	366	383	396	404	414	422	430	438	446	454

continued

Table 1. Continued.

Country	Units	14/15	15/16	16/17	17/18	18/19	19/20	20/21	21/22	22/23	23/24	24/25	25/26
	(mt)												
Importers, continued													
Cote d'Ivoire	(1000 mt)	1300	872	1049	1085	1160	1223	1276	1319	1348	1394	1449	1473
Nigeria	(1000 mt)	3500	2522	3137	3147	3116	3208	3374	3530	3660	3813	3915	4026
South Africa	(1000 mt)	980	989	990	1026	1033	1043	1062	1080	1086	1106	1097	1128
Senegal	(1000 mt)	1200	1003	1110	1138	1158	1185	1201	1224	1256	1292	1327	1364
Ghana	(1000 mt)	550	606	651	693	734	745	780	809	832	867	901	931
Cameroon	(1000 mt)	525	546	572	631	665	712	745	765	795	822	855	888
Mozambique	(1000 mt)	480	533	523	554	574	595	643	667	703	732	760	782
Guinea	(1000 mt)	300	359	390	427	439	454	469	488	499	517	531	543
Kenya	(1000 mt)	420	522	517	538	572	577	594	608	632	650	668	682
Tanzania	(1000 mt)	100	169	168	176	172	189	208	196	189	185	176	176
Sierra Leone	(1000 mt)	220	274	168	149	124	115	113	114	103	99	95	101
Mali	(1000 mt)	180	166	130	104	73	63	74	69	67	80	73	84
Liberia	(1000 mt)	340	361	383	405	425	444	468	490	518	540	561	589
Colombia	(1000 mt)	300	348	336	351	355	358	356	358	363	369	378	383
ECOWAS 7[a]	(1000 mt)	1436	1490	1585	1709	1815	1905	1998	2090	2186	2284	2389	2487
Cuba	(1000 mt)	483	505	517	523	525	526	535	542	546	552	562	566
Costa Rica	(1000 mt)	150	103	108	110	110	108	111	114	117	120	122	126
Dominican Republic	(1000 mt)	15	18	18	18	19	16	17	17	19	19	20	21
Guatemala	(1000 mt)	88	78	79	80	83	86	89	92	95	99	102	105
Honduras	(1000 mt)	134	150	144	145	145	144	147	149	152	155	159	163
Nicaragua	(1000 mt)	70	74	80	79	78	77	79	81	83	86	89	92
Panama	(1000 mt)	76	81	86	89	91	94	98	99	100	102	102	102
Chile	(1000 mt)	127	122	146	144	143	144	145	147	150	153	156	159
Paraguay	(1000 mt)	2	2	2	2	2	2	2	2	2	2	2	2
Peru	(1000 mt)	205	221	242	276	283	289	284	275	272	275	283	294
ROW and Residual	(1000 mt)	9393	7447	7394	7391	7290	7369	7484	7733	8009	8089	8178	8352
Total Imports	(1000 mt)	43093	41932	41895	42563	43165	43839	44614	45246	46027	46851	47568	48402

continued

Table 1. Continued.

Country	Units	14/15	15/16	16/17	17/18	18/19	19/20	20/21	21/22	22/23	23/24	24/25	25/26
	(mt)												
Prices													
International Rice Reference Price	(US$/mt)	420	369	458	472	496	518	522	530	534	539	541	545
U.S. FOB[b] Gulf Ports	(US$/mt)	518	508	540	552	559	575	581	583	585	590	603	610
U.S. No. 2 Medium FOB CA	(US$/mt)	877	799	828	831	832	834	835	837	839	840	842	845

[a] ECOWAS 7 = Economic Community of West African States.
[b] FOB = Free On Board.

Table 2. World rice supply and utilization, and macro data, 2014-2025.

Variable	Units	14/15	15/16	16/17	17/18	18/19	19/20	20/21	21/22	22/23	23/24	24/25	25/26
Area harvested	(1000 ha[a])	160,011	158,935	159,387	160,394	160,681	161,031	161,446	161,505	161,748	161,925	161,819	161,641
Yield	(mt/ha)	2.99	2.96	3.02	3.05	3.07	3.10	3.13	3.15	3.18	3.20	3.23	3.25
Production	(1000 mt)	478,261	470,129	481,422	489,095	493,853	499,173	505,508	509,360	514,436	518,848	522,549	525,841
Beginning stocks	(1000 mt)	107,487	103,866	89,351	83,755	81,167	79,257	79,281	81,488	83,611	86,413	89,108	91,097
Domestic supply	(1000 mt)	585,748	573,995	570,773	572,850	575,020	578,430	584,789	590,848	598,048	605,261	611,658	616,938
Consumption	(1000 mt)	480,121	484,374	486,893	491,672	495,844	499,298	503,493	507,456	511,868	516,394	520,808	524,864
Ending stocks	(1000 mt)	103,866	89,351	83,755	81,167	79,257	79,281	81,488	83,611	86,413	89,108	91,097	92,325
Domestic use	(1000 mt)	583,987	573,725	570,648	572,839	575,101	578,579	584,981	591,067	598,281	605,503	611,905	617,189
Total trade	(1000 mt)	43,093	41,932	41,895	42,563	43,165	43,839	44,614	45,246	46,027	46,851	47,568	48,402
Per capita use	(kilogram)	65.6	65.4	65.0	64.9	64.8	64.5	64.4	64.2	64.2	64.1	64.0	64.0
Percent stocks-to-use	(%)	21.6	18.4	17.2	16.5	16.0	15.9	16.2	16.5	16.9	17.3	17.5	17.6
Population growth	(%)	1.2	1.2	1.2	1.1	1.1	1.1	1.0	1.0	1.0	1.0	0.9	0.9
Real GDP growth	(%)	2.7	2.6	2.9	3.2	3.3	3.3	3.4	3.3	3.4	3.4	3.3	3.2

[a] ha = hectares; mt = metric tons.

Table 3. Detailed U.S. rice supply and utilization, and macro data, 2014-2025.

Variable	Units	14/15	15/16	16/17	17/18	18/19	19/20	20/21	21/22	22/23	23/24	24/25	25/26
Yield (rough basis)	(lb/acre)	7576.5	7469.5	7701.3	7798.4	7893.1	7984.6	8070.2	8146.6	8223.5	8301.7	8377.7	8444.5
Total harvested area	(1000 acre)	2933.0	2575.0	2662.5	2718.9	2742.6	2747.8	2747.8	2736.8	2722.4	2704.3	2716.9	2819.2
Supply (rough basis)	(mil. cwt[a])	278.7	265.3	269.2	271.4	274.5	275.9	275.5	274.5	273.8	273.0	274.7	286.2
Production	(mil. cwt)	222.2	192.3	205.0	212.0	216.5	219.4	221.8	223.0	223.9	224.5	227.6	238.1
Beginning stocks	(mil. cwt)	31.8	48.5	39.9	35.3	33.8	31.6	28.1	25.7	24.1	22.6	21.0	22.1
Imports	(mil. cwt)	24.7	24.4	24.2	24.1	24.3	24.9	25.7	25.9	25.8	26.0	26.1	26.1
Domestic use (rough basis)	(mil. cwt)	129.9	122.4	126.4	127.8	130.3	132.7	133.5	133.5	134.0	134.4	134.6	135.0
Food	(mil. cwt)	105.3	106.3	107.3	108.5	109.8	110.9	112.1	113.8	115.8	117.8	119.8	121.7
Seed	(mil. cwt)	3.2	3.2	3.3	3.4	3.4	3.4	3.4	3.4	3.4	3.3	3.4	3.5
Brewing	(mil. cwt)	18.8	18.9	18.9	19.1	19.2	19.3	19.4	19.5	19.6	19.6	19.4	19.5
Residual	(mil. cwt)	2.6	-6.0	-3.2	-3.2	-2.1	-1.0	-1.4	-3.3	-4.8	-6.3	-8.0	-9.7
Exports	(mil. cwt)	100.3	103.1	107.5	109.9	112.6	115.1	116.4	117.0	117.3	117.6	118.1	119.2
Total use	(mil. cwt)	230.2	225.4	233.8	237.7	242.9	247.8	249.9	250.4	251.2	252.0	252.7	254.1
Ending stocks	(mil. cwt)	48.5	39.9	35.3	33.8	31.6	28.1	25.7	24.1	22.6	21.0	22.1	32.1
Prices													
Loan rate	(US$/cwt)	6.50	6.50	6.50	6.50	6.50	6.50	6.50	6.50	6.50	6.50	6.50	6.50
Season ave. farm price	(US$/cwt)	13.30	13.20	13.69	13.84	13.93	14.15	14.22	14.09	14.16	15.23	17.17	17.77
Long-grain farm price	(US$/cwt)	11.90	11.53	12.60	12.86	13.12	13.40	13.51	13.38	13.48	14.45	16.26	16.85
Medium-grain farm price (Average)	(US$/cwt)	18.20	17.10	17.20	17.24	16.97	17.13	17.16	17.03	17.08	18.42	20.79	21.50
Japonica farm price	(US$/cwt)	21.40	20.46	20.16	20.18	19.76	19.85	19.83	19.65	19.64	21.02	23.46	24.19
Southern medium-grain farm price	(US$/cwt)	14.40	12.05	12.61	12.71	12.41	12.53	12.55	12.41	12.52	13.62	15.57	16.15

continued

Table 3. Continued.

Variable	Units	14/15	15/16	16/17	17/18	18/19	19/20	20/21	21/22	22/23	23/24	24/25	25/26
Prices, continued													
Reference prices:													
Long-grain farm price	(US$/cwt)	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00
Southern medium-grain farm price	(US$/cwt)	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00
Japonica	(US$/cwt)	16.10	16.10	16.10	16.10	16.10	16.10	16.10	16.10	16.10	16.10	16.10	16.10
Export price, FOB[b] Houston (U.S. No. 2)	(US$/cwt)	23.50	23.03	24.49	25.04	25.36	26.06	26.38	26.44	26.54	26.76	27.34	27.67
Medium-grain price, FOB CA (U.S. No. 2)	(US$/cwt)	39.78	36.25	37.56	37.68	37.72	37.82	37.87	37.98	38.06	38.11	38.17	38.31
Program payment	(US$/cwt)	1.52	2.23	1.21	0.96	0.76	0.54	0.46	0.55	0.47	0.02	0.00	0.00
Average world price (US$/cwt)	(US$/cwt)	10.61	9.40	10.10	10.45	10.83	11.26	11.46	11.66	11.80	11.98	12.18	12.27
Income factors:													
Production market value	(mil. US$)	3021	2547	2858	2992	3075	3166	3216	3204	3235	3483	3974	4300
Program payment	(mil. US$)	338	428	247	203	165	119	101	123	105	6	0	0
Total income	(mil. US$)	3359	2976	3106	3195	3240	3285	3317	3327	3340	3488	3974	4300
Market returns above variable cost	(US$/acre)	488	473	574	596	598	611	494	479	481	567	728	777
Total returns above variable cost	(US$/acre)	604	639	667	670	658	654	494	479	481	567	728	777
Per capita use	(lb)	28.7	13.25	13.35	13.54	13.56	13.61	13.56	13.51	13.44	13.43	13.38	13.31
Stocks-to-use ratio	(%)	0.21	17.15	19.51	17.84	16.47	15.68	15.37	14.88	14.63	14.24	14.12	14.57
Population growth	(%)	0.74	0.75	0.82	0.81	0.80	0.80	0.79	0.78	0.77	0.75	0.74	0.73
Real GDP growth	(%)	2.43	2.46	2.74	2.96	2.69	2.55	2.53	2.18	2.14	2.17	2.20	2.12

[a] mil. cwt = million hundred weight.
[b] FOB = Free On Board.

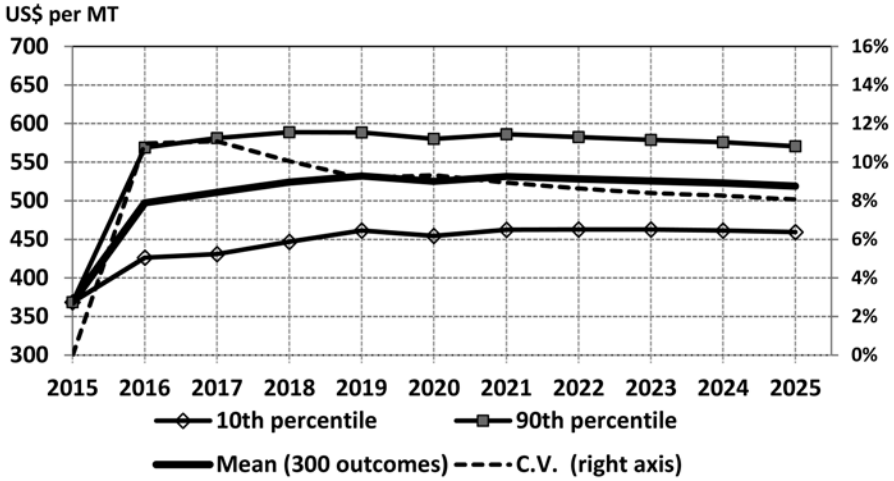

Fig. 1. Stochastic projections of long-grain rice international reference price (U.S. dollars; $/metric ton; mt), 2015-2025.

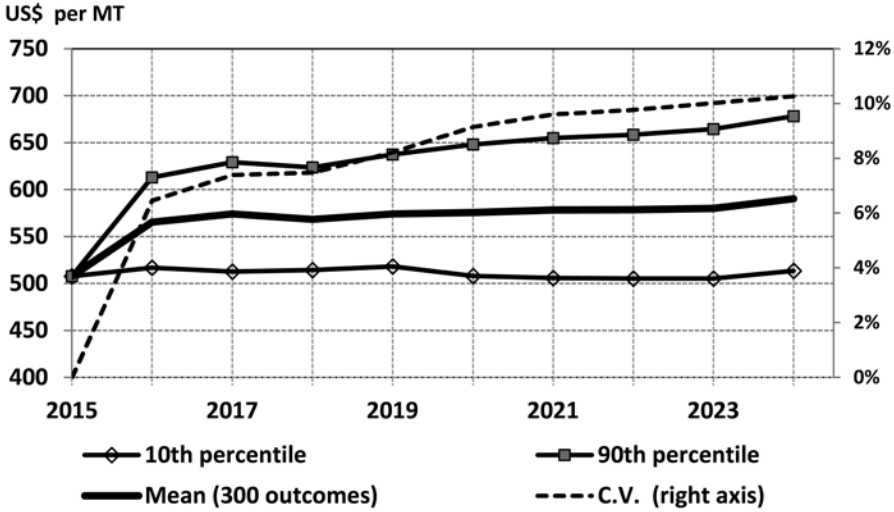

Fig. 2. Stochastic projections of U.S. long-grain rice free on board export price (U.S. dollars; $/metric ton; mt), 2015-2025.

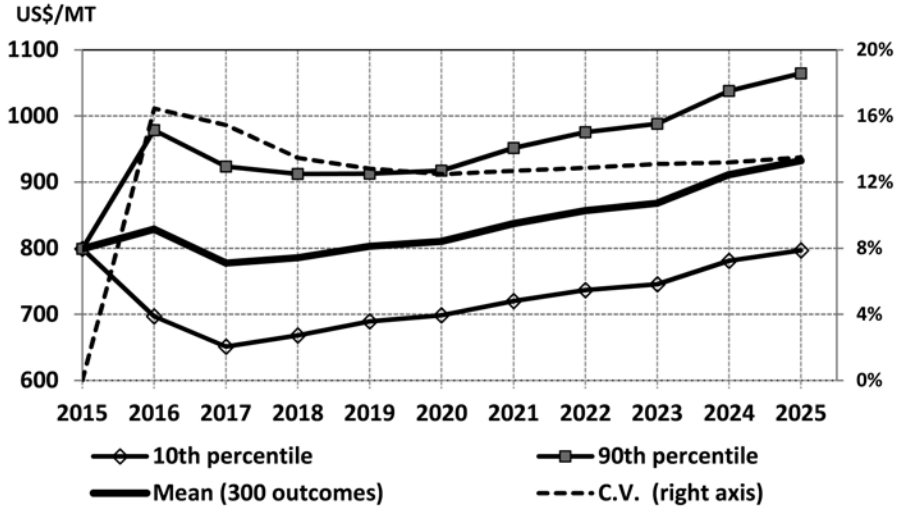

Fig. 3. Stochastic projections of medium-grain rice mill price, free on board California (U.S. dollars; $/metric ton; mt), 2015 -2025.

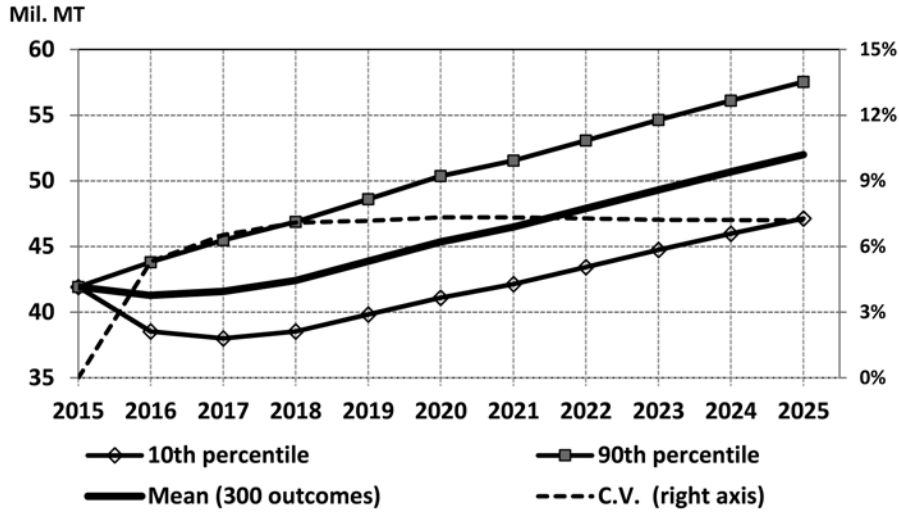

Fig. 4. Stochastic projections of world rice total trade (million metric tons; mil. mt), 2015-2025.

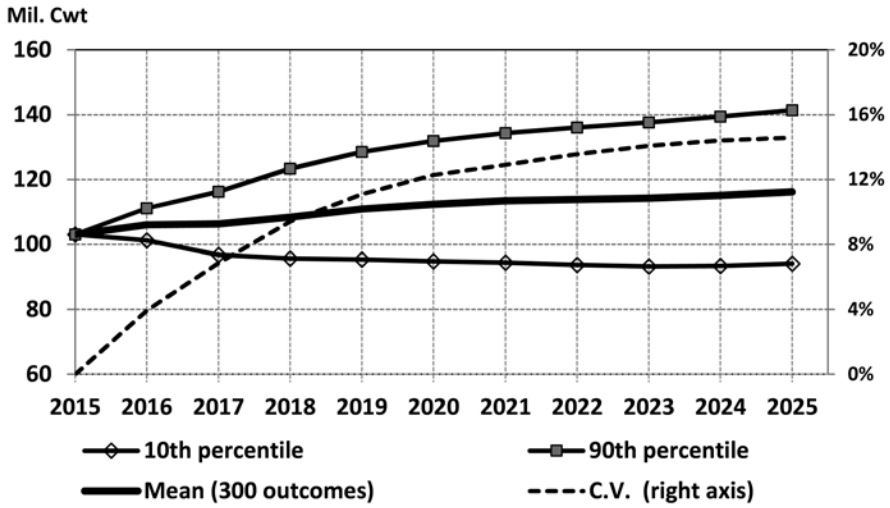

Fig. 5. Stochastic projections of U.S. rice total exports [million (mil.) hundredweight (cwt)], 2015-2025.

The Economics of Methane Emissions in Arkansas Rice Production

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ABSTRACT

This study sets out to estimate average county/parish and state level methane (CH_4) emissions per hectare as well as CH_4 efficiency levels (kg rice/kg CH_4 ha^{-1}) in rice production for Arkansas, Louisiana, and Mississippi in order to highlight spatial differences in CH_4 emission in rice production. Our findings suggest that on average Mississippi was the most efficient at converting CH_4 into rice (267.46 kg rice/kg CH_4 ha^{-1}), followed by Arkansas (189.92) and Louisiana (178.80). Specifically, Louisiana was negatively impacted by its large ratoon crop in terms of CH_4 use efficiency, with 38% of its primary rice crop being ratooned. Moreover, the Mississippi results should be interpreted with caution because seeding data, specifically the area seeded to hybrids and county level yields, are not as robust as those for Arkansas and Louisiana. Overall, these results provide rice buyers, producers, and consumers with important information about the spatial aspects of sustainability in rice production.

INTRODUCTION

Increased consumer demand for food products with lower greenhouse gas (GHG) emissions have prompted row crop producers to reduce GHG emissions associated with crop production. More importantly, agricultural producers face increasing demand and, in some cases, requirements from the private industry to reduce GHG emissions associated with crop production. To demonstrate, Wal-Mart recently announced a potential plan to label each of its products with a sustainability rating and subsequently requested that every Wal-Mart supplier provide its product's GHG footprint, a direct measure of climate impact (Wal-Mart Corporate-Sustainability Index, 2011). In response to these commercial pressures, agricultural producers and processors have sought to increase production efficiency with respect to GHG emissions. Particularly, rice production (from seed to farm gate) has been identified as a significant source of atmospheric methane (CH_4) emissions from U.S. agricultural production (U.S. Environmental Protection Agency, 2011). As a result, producers and large-scale purchasers of U.S. rice have attempted to increase the efficiency of GHG emissions in rice production. As such, this study estimates county/parish and state averages of CH_4 use efficiency (kg rice/kg CH_4

ha^{-1}) in Arkansas, Louisiana, and Mississippi in 2014 in order to provide consumers and large-scale buyers of rice more information about the spatial components related to sustainability in rice production.

PROCEDURES

Methane emissions from rice production were estimated in each of the 96 rice-growing counties/parishes in Arkansas, Louisiana, and Mississippi using a two-step approach, consistent with the Intergovernmental Panel on Climate Change (IPCC, 2006). In the first step, data from field research (Rogers et al., 2013; Brye et al., 2013) were used in a regression model to estimate representative CH_4 emission factors based on rice cultivar type (hybrid and conventional pure-line), soil texture (loamy and clayey), and crop rotation (rice-rice and soybean-rice). The field research was conducted in 2012 and 2013 at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC) near Stuttgart, Ark., on a DeWitt silt loam and at the Northeast Research and Extension Center (NEREC) at Keiser, Ark., on a Sharkey clay soil. At both locations, the study areas had previously been managed in a rice-soybean rotation for at least 15 years. Subsequently, in 2012 and 2013 at RREC, four replications of the conventional pure-line cultivars Taggart and Cheniere and the hybrid cultivar CLXL745 were sown following the previous crops of rice or soybean. In 2012, at NEREC, four replications of Taggart were sown following soybean as the previous crop; while in 2013, four replications of Taggart, Cheniere, and CLXL745 were sown following the previous crops of soybean or rice. Each year at each location, plots were outfitted with a 30-cm diameter, enclosed-headspace gas sampling chamber assemblage to measure CH_4 emissions.

Unlike previous studies, this experimental design allowed for a direct comparison of the effects of soil texture, cultivar type, and crop rotation on CH_4 emissions. Research efforts have identified a diel CH_4 emission pattern with soil texture, air and water temperature, soil organic carbon, and cultivar as contributing factors to overall CH_4 emissions. Furthermore, previous studies have quantified the proportion of CH_4 emissions by independently altering each factor mentioned above while holding the other two constant, leading to potentially biased estimates. The goal of this study was to holistically identify those factors contributing to CH_4 emissions as a result of three sources of variation—soil type, cultivar, and preceding crop.

The first step in this estimation process is to use a regression model specified for the parameter estimates given by:

$$Y_{ipst} = \alpha_0 + \alpha_{ips} X_{ipst} + u_{ispt} \qquad \text{Eq. (1)}$$

where Y_{ipst} is the CH_4 emissions (kg CH_4-C ha^{-1}) for cultivar i, under crop rotation p, grown on soil with texture s, in year t. The variable X_{ipst} is a categorical variable formed by the combination of soil texture (two types), cultivar type (two types: due to lack of degrees of freedom, both conventional cultivars were analyzed as conventional and not specific cultivar lines), and crop rotation. The eight categories formed are: (1)

conventional cultivar grown on clay soil following a rice-rice rotation, (2) conventional cultivar grown on clay soil following a soybean-rice rotation, (3) conventional cultivar grown on loamy soil following a rice-rice rotation, (4) conventional cultivar grown on loamy soil following a soybean-rice rotation, (5) hybrid cultivar grown on clay soil following a rice-rice rotation, (6) hybrid cultivar grown on clay soil following a soybean-rice rotation, (7) hybrid cultivar grown on loamy soil following a rice-rice rotation, and (8) hybrid cultivar grown on loamy soil following a soybean-rice rotation. The remaining influences on CH_4 emissions are captured by the error term and are assumed to be independent of the soil, the cultivar, and the rotation effects. By omitting one of the categories in X_{ipst} in Eq. (1), the parameter α_0 serves as the emission factor for the omitted category. Further, the seven α_{ips} parameters are the marginal differences between the omitted category and the category for which α_{ips} is estimated. The omitted category in this case is category 6—hybrid cultivar grown on clay soil following a soybean-rice rotation. Thus, the emission factor for a category not omitted is given by the summation of α_0 and the appropriate component of α_{ips}.

In the second step of the estimation process, the estimates derived from Eq. (1) are applied to all 96 rice-growing counties/parishes in Arkansas, Louisiana, and Mississippi to simulate their respective annual CH_4 emissions for the period 2002-2014, which were based on a 1000 simulations based on categorical variables in Eq. (1). This simulation is done by first synthesizing each county's (1) soil texture maps into percentages of loamy versus clayey soils, (2) historical seeding area between hybrid and conventional rice cultivars, and (3) percentage of rice area under different crop rotations. Ideally, a CH_4 measurement from each combination (crop rotation/cultivar type/soil texture) would be obtained from field plots in each county/parish. However, given the high cost of measuring CH_4 emissions, extrapolation is currently the most feasible alternative. Notably, data on the historical seeding area between hybrid and conventional rice cultivars at the county level were collected from various annual publications of the Proceedings of the Rice Technical Working Group. Soil texture data were collected from the Web Soil Survey (WSS) provided by the USDA Natural Resources Conservation Service (NRCS) (USDA-NRCS, 2015), and data on crop rotation were sourced from over twenty extension agents throughout the growing region since observed data on county/parish crop rotations are nonexistent.

The simulations recognized two sources of uncertainty and were modeled by random draws according to the hypothesized distributions. The first source is a result of uncertainty about the regression parameters from Eq. (1) since they are based on sample data. In each of the 1000 simulations, a vector of emission factors was drawn, assuming normality and using the covariance matrix of the estimated emission factors from Eq. (1). The second source of uncertainty is the randomness due to the additive error term of the regression model. This randomness is dealt with in two steps. First, for a given combination of soil texture, cultivar type, and crop rotation, the standard deviations ($SD_{u_{ipst}}$) for the error terms (u_{ipst}) in Eq. (1) were estimated, accounting for heteroscedasticity. A distribution of the error term ($\tilde{u}_{ips}$) was estimated for each of the eight categories (differing by the variance). Then, 1000 draws from a standard, normal

distribution were generated by a random number generator. This draw was multiplied by each of the eight $SD_{u_{ipst}}$ and added to the appropriate simulated sample mean to give the simulated CH_4 emissions (kg CH_4-C ha^1) for each unique combination of *ips*. This procedure recognizes that the error term in Eq. (1) is heteroscedastic across the eight categories in X_{ipst}. Using these simulated emissions, the CH_4 emitted from each county was computed using the observed proportions of cultivars, soil types, rotations and acres (hectares) seeded to rice observed for each county in 2014. This computation generates an extrapolation to all 96 rice-growing counties/parishes in Arkansas, Louisiana, and Mississippi in order to simulate their respective annual CH_4 emissions. The total simulated CH_4 emissions ($\widetilde{\mathrm{CH}}_{jt}^1$) for the primary rice crop in the j^h county/parish in 2014 is represented as:

$$\widetilde{\mathrm{CH}}_j^1 = \sum_i \sum_p \sum_s \left[Ha_{jips} \left(\hat{\alpha}_{ips} + \hat{\alpha}_0 + \tilde{u}_{ips} \right) \right] \qquad \text{Eq. (2)}$$

where Ha_{jips} is the total area of rice seeded to cultivar *i*, under crop rotation *p*, and grown on a soil with texture *s*, and $\widehat{\alpha}_{ips}$ and $\hat{\alpha}_0$ are estimated from Eq. (1). In the summation (2), the $\widehat{\alpha}_{ips}$ referring to a hybrid cultivar grown on clay soil following a soybean-rice rotation is zero.

Previous literature suggests that ratoon rice crops generate CH_4 at a considerably higher rate than primary crops. This happens because the amount of organic carbon available for anaerobic decomposition (from the crop residue of the primary crop) is considerably higher during the ratoon crop production relative to the primary crop (Wang et al., 2013). Currently, the climatic conditions of Texas, Louisiana, Arkansas, and Florida typically allow for ratoon crop production. Previous studies in these areas estimate the seasonal emission factor for primary and ratoon crops to be 237 kg CH_4-C ha^{-1} and 780 kg CH_4-C ha^{-1}, respectively (USEPA, 2015). Thus, CH_4 emissions from ratoon crops are about 3.29 (780 kg /237 kg) times that of the primary crop. The total emissions from ratoon crop ($\widetilde{\mathrm{CH}}_j^2$) in the j^h county/parish is therefore calculated as:

$$\widetilde{\mathrm{CH}}_j^2 = 3.29 \left(\widetilde{\mathrm{CH}}_j^1 / Ha_j^1 \right) Ha_j^2 \qquad \text{Eq. (3)}$$

where Ha_j^1 and Ha_j^2 are the total area seeded to primary and ratoon rice in the j^h county/parish. Thus, the total emissions of the j^h county/parish are:

$$\widetilde{\mathrm{CH}}_{jt} = \widetilde{\mathrm{CH}}_{jt}^1 + \widetilde{\mathrm{CH}}_{jt}^2 \qquad \text{Eq. (4)}$$

where total emissions for the j^h county/parish ($\widetilde{\mathrm{CH}}_{jt}$) is the sum the emissions from the primary crop ($\widetilde{\mathrm{CH}}_{jt}^1$) and the ratoon crop ($\widetilde{\mathrm{CH}}_{jt}^2$). Finally, using the 2014 NASS-reported (USDA-NASS, 2015a) rice production quantities (Q_{jt}) in kilograms for each of the 96 counties/parishes, we also calculated the amount (kg) of rice produced per CH_4 emissions for the j^h county/parish in year 2014 as:

$$\mathrm{QCH}_j = \mathrm{Q}_j / \widetilde{\mathrm{CH}}_j \qquad \text{Eq. (5)}$$

From these calculations we identify: 1) those counties/parishes with the largest net CH_4 emissions, 2) the counties/parishes with the best efficiency in terms of kg rice/kg CH_4,

and 3) state averages of kg of rice/kg CH_4-C ha^{-1} to provide state aggregates. Given the fact that rice mills often source from various counties/parishes from one state, state averages eliminate the need for a potential buyer of rice to determine what county/parish it originated in, but rather which state.

RESULTS AND DISCUSSION

The regression estimates from Eq. (1) are displayed in Table 1. The R^2 value indicates that 91% of the variation in CH_4 emissions is explained by the change across the eight categories formed by the combination of soil texture, cultivar type, and crop rotation. The results from this regression indicate that the driving factor for CH_4 emissions appears to be soil texture with loamy soils emitting 987% more than clayey soils. The next largest factor in CH_4 emissions is cultivar type with the conventional emitting 40% more CH_4 than hybrids, and crop rotation with rice-rice rotations emitting 39% more CH_4 than rice-soybean. Thus, hybrids grown on clayey soils after soybeans had the lowest season-long CH_4 emissions (5.82 kg CH_4-ha^{-1}); while conventionals grown on loamy soil after rice had the largest CH_4 emissions (181.95 kg CH_4-ha^{-1}).

County-level rice production per CH_4 emissions for Arkansas, Louisiana, and Mississippi in 2014 are presented in Tables 2, 3, and 4. From an average efficiency standpoint (kg rice/kg CH_4- ha^{-1}), Mississippi was the most efficient (267.46), followed by Arkansas (189.92), and Louisiana (178.80). Accordingly, Louisiana was negatively affected in terms of the efficiency of CH_4 use by its large ratoon crop (38% ratooned area as the percent of primary growth area, USEPA, 2015). To ensure unbiased comparisons, we also estimated a weighted average by rice production (volume by location). That is, several low-yielding counties/parishes could be outliers and thus skew the means. Tables 2, 3, and 4 show that Arkansas again had the second-highest CH_4 use efficiency (200.06 kg rice/kg CH_4 ha^{-1}), behind Mississippi and ahead of Louisiana.

The results from Mississippi in this study should be observed with caution given the poor data availability in 2014 (Table 4). In 2014, USDA-NASS (2015b) reports that 50% of counties in Mississippi have the same rice yield. This observation is a result of the low number of rice producers in a county, and the fact that NASS must keep the data of individual producers anonymous. Furthermore, Mississippi did not report hybrid adoption at the county level, but only reported it at the state level for 2014. While the county-level results are listed in the aforementioned tables, the state-level results may be more robust because rice mills may not know the county of origin for the rice they are selling in bulk, but may be surer of the state of origin. Thus, the aggregate results of state comparisons is necessary to mimic the decision-making of rice buyers and millers. Even more, on the average unweighted results, Arkansas was 25% more efficient in terms of kg rice/kg CH_4-ha^{-1} than Louisiana, and 108% less efficient than Mississippi (Tables 2, 3, and 4). Notably, the model used for the extrapolation is based on data solely from Arkansas locations. Similar experiments in Mississippi and Louisiana would likely generate somewhat different parameter estimates and therefore different CH_4 estimates.

SIGNIFICANCE OF FINDINGS

Understanding the CH_4 use efficiency of rice across states is important for a number of reasons: (1) buyers of rice may start paying premiums for rice from those states that are more efficient in terms of how much rice is produced per unit of CH_4 released, in order to meet the growing consumer demand for environmentally friendly foods; (2) if a carbon policy, i.e., tax/offset program, is instituted, the data and the results generated from this study will provide producers and policy-makers at the state level with the information they need to respond accordingly; (3) this study illustrates the largely negative effect of ratooning rice on the overall efficiency of CH_4 production per kilogram of rice produced, specifically in large ratooning states like Louisiana; and (4) these results can provide a spatial component that gives rice producers information on where they stand in the increasingly demanding world of sustainability.

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Table 1. Regression estimates.

Rice type/soil texture/ crop rotation	Estimated coefficient[a]
(number of observations)	
Conventional clay rice	16.32***
(n = 8)	(-2.53)
Conventional clay soybean	11.07**
(n = 12)	(-4.44)
Conventional loamy rice	176.13***
(n = 16)	(-7.36)
Conventional loamy soybean	147.92***
(n = 16)	(-8.75)
Hybrid clay rice	8.77***
(n = 4)	(-3.12)
Hybrid loamy rice	151.30***
(n = 8)	(-7.35)
Hybrid loamy soybean	66.90***
(n = 8)	(-8.58)
Constant hybrid clay soybean	5.82***
(n = 4)	(-1.07)
R^2	0.912

[a] Significance levels: * = $P < 0.10$, ** = $P < 0.05$, *** = $P < 0.01$. Standard errors of the estimates are in parentheses.

Table 2. 2014 Arkansas county level methane (CH_4) efficiency (kg rice/ kg CH_4-C ha^{-1}) estimates[a].

County	Soil texture		Seeded area[b]	Hybrid adoption	Rice yield[b]	CH_4 efficiency	
	Clayey	Loamy				Mean[c]	SD[d]
	(%)		(acre)	(%)	(lb/acre)	(kg rice/kg CH_4-C ha^{-1})	
Pope	1.23	98.77	2204 (892)	54.10	8731 (9,786)	65.47	0.39
Faulkner	4.40	95.60	2582 (1,045)	51.00	9359 (10,490)	71.05	0.42
Lafayette	24.36	75.64	4433 (1,794)	40.00	9005 (10,093)	78.77	0.62
Pulaski	15.54	84.46	4169 (1,687)	81.92	9396 (10,531)	94.26	0.69
Lawrence	12.70	87.30	99,922 (40,437)	15.80	18,543 (20,784)	128.89	9.05
Craighead	9.82	90.18	71,510 (28,939)	15.19	20,699 (23,200)	139.67	6.01
Independence	4.39	95.61	12,746 (5,158)	26.74	20,955 (23,487)	141.68	1.02
Randolph	5.99	94.01	35,657 (14,430)	36.49	20,369 (22,831)	146.12	2.71
Jackson	13.29	86.71	104,194 (42,166)	24.77	20,613 (23,104)	149.92	7.83
Drew	10.83	89.17	11,312 (4,578)	41.67	20,421 (22,889)	157.06	0.80
White	10.91	89.09	13,193 (5,339)	70.03	19,167 (21,483)	171.19	1.04
Clay	15.74	84.26	81,505 (32,984)	34.79	22,185 (24,866)	173.09	5.19
Monroe	28.75	71.25	59,493 (24,076)	25.97	20,164 (22,601)	173.12	3.82
Ashley	12.32	87.68	1,1182 (4,525)	67.79	19,671 (22,048)	175.88	0.83
Arkansas	6.94	93.06	91,155 (36,889)	56.68	22,140 (24,,816)	177.13	6.11
St. Francis	37.02	62.98	38,445 (15,558)	18.29	19,973 (22,387)	182.45	2.41
Greene	23.66	76.34	78,404 (31,729)	42.62	20,878 (23,401)	183.65	4.70
Prairie	18.17	81.83	63,639 (25,754)	49.39	21,386 (23,970)	183.75	3.91
Poinsett	32.54	67.46	121,568 (49,197)	13.31	22,020 (24,681)	186.42	7.60
Lee	27.71	72.29	29,919 (12,108)	37.62	20,977 (23,512)	188.20	1.74
Woodruff	34.05	65.95	61,925 (25,060)	36.29	20,080 (22,507)	192.70	3.52
Cross	31.98	68.02	88,036 (35,627)	26.41	21,936 (24,587)	195.86	4.99
Phillips	40.04	59.96	32,643 (13,210)	39.51	19,436 (21,,785)	204.35	1.76
Lonoke	18.17	81.83	89,731 (36,313)	69.81	21,804 (24,439)	209.24	5.72
Lincoln	34.15	65.85	21,515 (8,707)	72.49	20,974 (23,509)	245.44	1.19
Jefferson	34.15	65.85	72,464 (29,325)	80.21	20,757 (23,265)	254.73	4.29
Desha	59.06	40.94	25,266 (10,225)	35.41	20,730 (23,235)	283.71	1.05
Mississippi	61.12	38.88	53,540 (21,667)	26.30	22,574 (25,302)	305.50	2.13
Crittenden	74.60	25.40	51,037 (20,654)	53.91	19,842 (22,240)	415.54	1.71

continued

Table 2. Continued.

County	Soil texture		Seeded area[b]	Hybrid adoption	Rice yield[b]	CH_4 efficiency	
	Clayey	Loamy				Mean[c]	SD[d]
	(%)		(acre)	(%)	(lb/acre)	(kg rice/kg CH_4-C ha^{-1})	
Chicot	70.77	29.23	34,839 (14,099)	65.04	20,538 (23,020)	422.69	1.13
Average	25.81	74.19	48,941 (198056)	43.65	19,177 (21,495)	189.92	3.15
Weighted avg. by lb	-	-	-	-	-	200.06	-
Weighted avg. by acre	-	-	-	-	-	199.12	-

[a] 77.05% of rice in Arkansas is assumed to be grown under a rice-soybean rotation in 2014.
[b] Equivalent metric units (ha and kg/ha) are in parentheses.
[c] Ordered from lowest efficiency level to highest.
[d] Standard deviations (SD) based on 1000 simulations.

Table 3. 2014 Louisiana parish level methane (CH_4) efficiency (kg rice/ kg CH_4-C ha^{-1}) estimates[a].

Parish	Soil texture		Rice-soybean rotation	Seeded area[b]	Ratoon crop[b]	Hybrid adoption	Rice yield[a]	CH_4 efficiency	
	Clayey	Loamy						Mean[c]	SD[d]
	(%)			(acres)		(%)	(lb/acre)	(kg rice/kg CH_4-C ha^{-1})	
Lafayette	9.53	0.00	71.86	534 (216)	502 (203)	10.69	8407 (9,423)	28.37	0.21
La Salle	12.52	33.74	71.86	554 (224)	0	0.00	8236 (9,231)	53.17	0.13
Rapides	20.33	35.76	71.86	11,001 (4,452)	0	0.00	7683 (8,612)	53.53	2.45
Ouachita	19.84	33.47	71.86	9175 (3713)	0	0.00	8189 (9,179)	56.77	1.93
Natchitoches	26.49	45.50	71.86	3813 (1,543)	0	21.56	8742 (9,798)	71.02	0.57
Allen	0.00	16.38	71.86	15,437 (6,247)	2454 (993)	35.99	18,157 (20,351)	104.94	1.55
Acadia	9.10	0.00	60.61	85,444 (34,578)	24,832 (10,049)	18.37	20,682 (23,181)	105.71	7.95
Jefferson Davis	14.71	0.71	60.61	83,484 (33,785)	23,001 (9,308)	32.84	19,082 (21,388)	110.04	7.07
Franklin	22.67	0.77	100.00	3005 (1,216)	0	82.66	9016 (10,106)	112.32	0.60
Beauregard	3.89	30.91	71.86	1248 (505)	613 (248)	58.77	21,772 (24,403)	112.64	0.13
Evangeline	6.97	4.78	60.61	45,905 (18,577)	5548 (2,245)	40.41	19,872 (22,274)	124.91	3.42

continued

Table 3. Continued.

Parish	Soil texture		Rice-soybean rotation	Seeded area[b]	Ratoon crop[b]	Hybrid adoption	Rice yield[a]	CH_4 efficiency	
	Clayey	Loamy						Mean[c]	SD[d]
	(%)			(acres)		(%)	(lb/acre)	(kg rice/kg CH_4-C ha^{-1})	
Calcasieu	8.27	2.32	71.86	15,212 (6,156)	1789 (724)	33.62	19,726 (22,110)	125.90	1.26
Vermilion	31.25	0.89	60.61	53,427 (21,621)	12,291 (4,974)	9.79	19,404 (21,749)	126.64	4.28
Catahoula	61.06	9.99	71.86	1300 (526)	0	43.85	8684 (9,734)	127.06	0.12
St. Landry	45.76	2.81	60.61	26,062 (10,547)	4008 (1,622)	10.63	19,219 (21,542)	161.18	1.66
Morehouse	32.61	4.04	71.86	37,617 (15,223)	0	22.33	20,138 (22,572)	175.97	2.27
West Carroll	24.46	0.00	71.86	2155 (872)	0	74.74	18,286 (20,496)	188.50	0.15
East Carroll	86.39	4.25	71.86	1589 (643)	0	36.71	8324 (9,330)	215.59	0.13
Richland	32.96	1.19	100.00	5614 (2,272)	0	48.64	20,645 (23,140)	224.83	0.37
Cameron	71.36	6.87	71.86	11,834 (4,789)	3032 (1,227)	11.05	19,254 (21,581)	233.07	0.70
West Baton Rouge	69.82	1.11	71.86	576 (233)	0	100.00	9818 (11,005)	247.98	0.04
Tensas	88.34	3.77	71.86	3141 (1,271)	0	40.86	9001 (10,089)	255.90	0.24
Iberia	57.94	0.00	71.86	1127 (456)	0	18.00	21,134 (23,688)	257.85	0.05
Avoyelles	64.24	6.21	71.86	11,987 (4,851)	114 (46)	24.19	19,953 (22,364)	277.61	0.52
St. Martin	65.79	0.00	71.86	3,437 (1,391)	771 (312)	62.35	21,998 (24,657)	319.65	0.13
Madison	85.37	0.25	71.86	7319 (2,962)	0	0.00	18,044 (20,225)	369.82	0.40
Concordia	84.72	1.18	71.86	9790 (3,962)	230 (93)	58.94	21,190 (23,751)	586.67	0.28
Average	29.05	11.21	71.86	19,761 (7,997)	3717 (1,504)	32.98	14,921 (16,724)	178.80	1.43
Weighted avg. by lb	-	-	-	-	-	-	-	149.34	-
Weighted avg. by acre	-	-	-	-	-	-	-	146.14	-

[a] A five-year average (2010-2014) was used for the area under ratoon.
[b] Equivalent metric units (ha and kg/ha) are in parentheses.
[c] Ordered from lowest efficiency level to highest.
[d] Standard deviations (SD) based on 1000 simulations.

Table 4. 2014 Mississippi county level methane (CH_4) efficiency (kg rice/ kg CH_4-C ha^{-1}) estimates[a].

County	Soil texture		Seeded area[b]	Rice yield[b]	CH_4 efficiency	
	Clayey	Loamy			Mean[c]	SD[d]
	-------- (%)	--------	(acre)	(lb/acre)	(kg rice/ kg CH_4-C ha^{-1})	
Grenada	1.89	25.19	282 (114)	11,166 (12,515)	83.01	0.05
Tate	3.56	10.01	934 (378)	11,166 (12,515)	84.23	0.16
Panola	6.07	14.24	5523 (2,235)	11,166 (12,515)	86.13	0.95
Holmes	13.37	12.85	121 (49)	11,166 (12,515)	92.17	0.02
Desoto	26.66	4.34	1191 (482)	11,166 (12,515)	105.68	0.16
Tallahatchie	35.53	6.14	6963 (2,818)	20,544 (23,027)	215.50	0.47
Humphreys	76.22	4.72	1475 (597)	11,166 (12,515)	232.82	0.12
Sharkey	87.55	7.39	432 (175)	11,166 (12,,515)	321.24	0.03
Sunflower	65.33	8.60	13,635 (5,518)	20,096 (22,525)	331.43	0.65
Leflore	67.21	2.05	3904 (1,580)	19,511 (21,869)	333.88	0.19
Issaquena	92.19	4.75	1114 (451)	11,166 (12,515)	380.32	0.09
Coahoma	70.93	19.26	8110 (3,282)	21,087 (23,635)	389.67	0.35
Quitman	74.05	11.20	8765 (3,547)	19,917 (22,324)	394.58	0.39
Bolivar	78.90	6.13	33,735 (13,652)	20,876 (23,399)	465.64	1.41
Tunica	80.45	8.00	24,602 (9,956)	21,326 (23,903)	495.61	1.01
Washington	81.96	14.10	11,480 (4,646)	21,148 (23,704)	512.41	0.47
Average	51.99	9.66	7386 (2,988)	15,512 (17,386)	267.46	0.40
Weighted avg. by kg	-	-	-	-	416.18	-
Weighted avg. by ha	-	-	-	-	403.60	-

[a] The Rice Technical Working Group Mississippi seeding report denoted only state aggregate level of hybrid adoption of 38% and not county level. Thus, this study assumes each county had 38% adoption. All rice in Mississippi is assumed to be under a soybean-rice rotation.

[b] Equivalent metric units (ha and kg/ha) are in parentheses.

[c] Ordered from lowest efficiency level to highest.

[d] Standard deviations (SD) based on 1000 simulations. NASS uses yield estimates of 11,166 lb/acre for several counties given the low number of rice producers in each county, to prevent a specific rice producer being identified. The average for the crop reporting district is used in these cases.

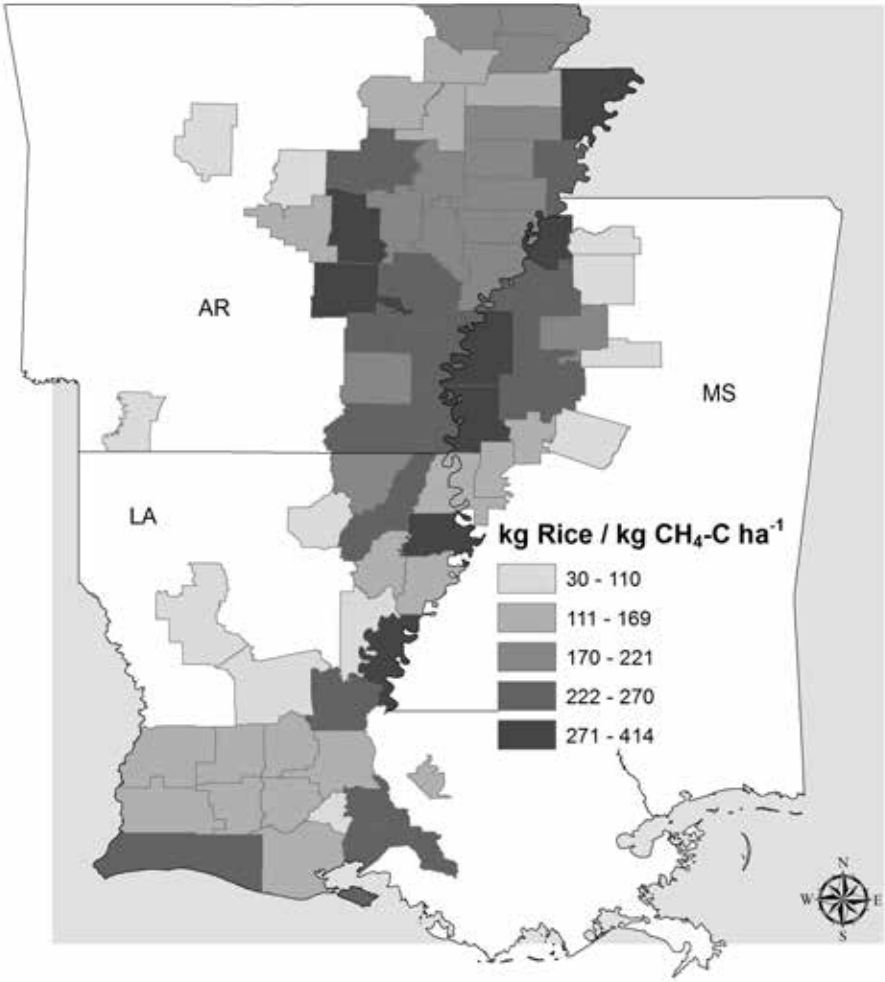

Fig. 1. Methane emission efficiency in rice production by county, 2014.

DIVISION OF AGRICULTURE

RESEARCH & EXTENSION

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