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B. R. Wells Arkansas Rice Research Studies 2016

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B.R. Wells

Arkansas Rice Research Studies 2016

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

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Cover Photo: Dr. Bobby R. Wells was posthumously inducted into the Arkansas Agriculture Hall of Fame at the 29th Annual Induction Ceremony on March 3, 2017 at the Embassy Suites in Little Rock, Arkansas. Photo credit: Fred Miller, University of Arkansas System Division of Agriculture Communications.

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Research Studies
2016

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

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

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

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

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

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

Among the awards Wells received were the Outstanding Faculty Award from the Department of Agronomy (1981), the Distinguished Rice Research and/or Education Award from the Rice Technical Working Group (1988), and the Outstanding Researcher Award from the Arkansas Association of Cooperative Extension Specialists (1992). He was named a Fellow in the American Society of Agronomy (1993) and 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. The name of this publication was modified in 2014 to the B.R. Wells Arkansas Rice Research Studies.

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.

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Trends in Arkansas Rice Production, 2016

J.T. Hardke[1]

Abstract

Arkansas is the leading rice producer in the United States. The state represents 47.0% of total U.S. rice production and 49.1% of the total acres planted to rice in 2016. 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 cultivar acreage distribution across Arkansas. Other data was obtained from the USDA National Agricultural Statistics Service.

Introduction

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

[1] Rice Extension Agronomist, Department of Crop, Soil, and Environmental Sciences, Rice Research and Extension Center, 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, 2017). 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 (RT) CLXL745 was the most widely planted cultivar in 2016 at 22.3% of the acreage, followed by Roy J (18.2%), RTXL753 (15.2%), CL151 (13.2%), LaKast (7.9%), Jupiter (6.3%), RTCLXL729 (3.6%), CL111 (1.6%), Mermentau (1.6%), and RTCLXP756 (1.6%). Additional cultivars of importance in 2016, though not shown in the table, were CL271, Wells, Cheniere, CL163, Taggart, and RTXL723.

Arkansas planted 1,546,000 acres of rice in 2016 which accounted for 49.1% of the total U.S. rice crop in 2016 (Table 2). The state-average yield of 6920 lb/acre (154 bu/acre) represented a 420 lb/acre reduction compared to 2015. This represented the lowest state average yield for Arkansas since 2011. High nighttime temperatures during late July and early August affecting pollination and grain fill appeared largely responsible for the decline in grain yield. Final harvested acreage in 2016 totaled 1,521,000. The total rice produced in Arkansas during 2016 was 105.31 million hundredweight (cwt). This represents 47.0% of the 224.1 million cwt produced in the U.S. during 2016. Over the past 3 years, Arkansas has produced 48.8% of all rice produced in the U.S. The six largest rice-producing counties by acreage in Arkansas during 2016 included Arkansas, Poinsett, Jackson, Lawrence, Cross, and Lonoke, representing 34.8% of the state's total rice acreage (Table 1).

Planting in 2016 began well ahead of the 5-year state average due to dry, moderate conditions (Fig. 1). Planting progress had reached 55% by 17 April compared to 13% planting progress averaged across the previous 5 years. Continued favorable conditions resulted in planting progress reaching 87% by 1 May compared to 44% in the 5-year average. Hot and dry conditions with little measurable rainfall during June and July resulted in rapid crop development. As harvest began, an abnormal rainy period during mid-August delayed harvest compared to actual crop maturity. However by 11 September, harvest progress had reached 52% compared to only 34% in the 5-year average (Fig. 2). About 84% of the crop had been harvested by 25 September compared with 48% harvest progress on the same date in previous years. Harvest progress was complete (100%) by 30 October.

Over 60% of the rice produced in Arkansas was planted using conventional tillage methods in 2016 (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 (35.3%) or no-till (3.7%) systems. True no-till rice production is not common but is done in a few select regions of the state.

The majority (48.3%) of rice is still produced on silt loam soils (Table 3). Rice production on clay or clay loam soils (23.9% and 20.6%, 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 68.4% of the rice acreage (Table 3). Approximately 20% of the acreage in 2016 was planted following rice, with the remainder made up of rotation with other crops including cotton, corn, grain sorghum, wheat, and fallow. The majority of the rice in Arkansas is produced in a dry-seeded, delayed-flood system with only 5.4% using a water-seeded system. Annually, approximately 85% of all the Arkansas rice acreage is drill-seeded with the remaining acreage broadcast-seeded (dry-seeded and water-seeded).

Irrigation water is one of the most precious resources for rice producers in Arkansas. Reports of diminishing supplies have prompted many producers to develop reservoir and/or tailwater recovery systems to reduce the "waste" by collecting all available water and re-using. Simultaneously, producers have tried to implement other conservation techniques to preserve the resource vital to continued production. Groundwater is used to irrigate 74.1% of the rice acreage in Arkansas with the remaining 25.9% irrigated with surface water obtained from reservoirs or streams and bayous (Table 3).

During the mid-1990s, the University of Arkansas System Division of Agriculture began educating producers on multiple-inlet irrigation which uses poly-tubing as a means of irrigating rice to conserve water and labor. As of 2016, rice farmers utilize this practice on 33.1% 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 and is increasing in interest as a means to reduce pumping costs and water use; but the practice accounts for only 2.2% of acreage at this time. Additional interest has risen in growing rice in a furrow-irrigated system as is common with soybean or corn as a means to simplify crop rotation and management and currently accounts for 2.7% of acreage.

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 2016, 44.0% of the acreage was burned, 43.8% was tilled, 25.2% was rolled, and 21.7% 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 2016, as in 2015, burned acreage saw a noticeable rise 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 54.8% of rice acres in 2016 (Table 3). Conditions favorable for the development of disease did not occur until late in the growing season due to predominantly hot and dry conditions. Approximately 41% of rice acres received a foliar insecticide application due to rice stink bug infestation levels which were slightly higher than 2015. Insecticide seed treatments were used on 75.9% 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.

Clearfield rice continues to play a significant role in rice production in Arkansas. This technology (all cultivars combined) accounted for 45% of the total rice acreage in 2016 (Fig. 3). Proper stewardship of this technology will be the key to its continued success on the majority of rice acres. In areas where stewardship has been poor, imadazolinone-resistant barnyardgrass has been discovered. Evidence of these resistant populations may have served to reduce the number of Clearfield acres by emphasizing the negative effects of improper technology management. In addition, multiple years of this technology and crop rotation have likely cleaned up many red rice fields to the point where they can be safely returned to conventional rice production.

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 162 bu/acre in 2014-2016, an increase of 42 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, all of the county agents who participated in this survey, the University of Arkansas System Division of Agriculture for support, and the members of the Rice Agronomy crew: Donna Frizzell, Eduardo Castaneda-Gonzalez, Garrett Lee, Tara Clayton, Chuck Pipkins, Ralph Mazzanti, and Ron Baker.

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Table 1. 2016 Arkansas

	Harvested acreage[a]		Medium-grain		Long-grain	
County	**2015**	**2016**	**Jupiter**	**Others[b]**	**CL111**	**CL151**
Arkansas	86,669	90,193	3299	451	1735	8896
Ashley	9105	8923	705	0	0	0
Chicot	27,057	35,524	0	0	3414	746
Clay	69,905	82,535	6144	986	3018	26,617
Craighead	66,874	70,876	10,222	0	0	17,484
Crittenden	43,842	63,483	1561	1881	0	2752
Cross	84,001	99,540	7582	0	3052	14,843
Desha	17,226	21,509	2440	813	0	0
Drew	9550	13,590	0	0	0	0
Faulkner	511	3552	0	0	0	355
Greene	66,208	80,237	2647	72	790	29,692
Independence	9974	10,805	255	0	0	1125
Jackson	82,216	113,446	9687	7013	3116	15,937
Jefferson	64,767	75,313	696	0	0	3731
Lafayette	3546	4751	0	0	0	950
Lawrence	91,554	104,971	2946	12,819	1595	17,448
Lee	21,744	25,228	1136	0	328	5591
Lincoln	21,016	22,872	0	0	434	434
Lonoke	80,916	90,233	1210	187	1034	5065
Mississippi	47,953	64,018	1053	0	0	0
Monroe	48,728	52,591	2160	0	0	1180
Phillips	16,094	32,151	279	0	400	400
Poinsett	110,824	121,335	21,760	979	1336	29,780
Pope	2186	2798	0	0	0	0
Prairie	61,743	64,137	7655	741	2632	2777
Pulaski	3799	3920	0	0	0	392
Randolph	30,009	33,646	8945	0	967	2441
St. Francis	37,462	42,451	57	2854	20	5901
White	10,073	9569	1150	0	0	0
Woodruff	50,874	61,186	2720	492	836	6180
Others[c]	2746	8187	0	0	0	736
Unaccounted[d]	5596	7433				
2016 Total		1,521,000	96,309	29,288	24,706	201,452
2016 Percent		100	6.33	1.93	1.62	13.24
2015 Total	1,286,000		184,910	51,076	48,751	159,837
2015 Percent	100		14.38	3.97	3.79	12.43

[a] Harvested acreage. Source: USDA-NASS, 2017.

[b] Other cultivars: AB647, Antonio, Catahoula, Cheniere, Cocodrie, CL152, CL153, CL163, CL172, CL271, CL272, Caffey, Della-2, Diamond, Francis, Jazzman-2, Presidio, Rex, RTXL723, RTXL760, RTXP754, Spring, Taggart, Titan, and Wells.

[c] Other counties: Clark, Conway, Franklin, Hot Spring, Little River, Miller, 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.

[g] NA = not applicable.

harvested rice acreage summary.

Long-grain							
LaKast	Mermentau	RTCL XL729	RTCL XL745	RTCL XL756	RTCL XL753	Roy J	Others[b]
5868	3	1182	30,599	2206	21,481	9780	4693
0	0	740	2684	2388	0	2406	0
549	3610	5011	9531	4983	2,507	738	4434
21,797	0	0	13,511	0	3,790	2946	3724
0	0	0	6503	0	18,105	18,562	0
449	0	3577	10,339	816	12,175	26,067	3867
15,363	357	687	8496	516	12,424	29,845	6375
1333	0	312	4874	1248	3,459	3224	3805
0	0	1224	4438	3949	0	3979	0
0	0	0	1243	0	1,066	533	355
0	0	0	32,352	0	8,496	132	6056
0	4584	0	3577	0	0	1264	0
12,816	0	701	23,842	1019	9,643	24,454	5219
23,477	0	2985	17,162	0	13,431	5969	7862
0	0	0	1900	0	1,900	0	0
2361	2214	0	27,219	1239	20,938	3490	12,703
5184	131	0	328	0	131	12,102	296
0	0	434	2818	5203	13,550	0	0
0	0	8580	35,430	0	18,270	10,488	9,968
0	67	0	32,150	0	23,862	6751	134
6419	0	6631	5878	0	10,285	18,042	1995
5005	7728	801	801	0	1,301	14,635	801
3972	2444	0	12,666	0	7,456	29,409	11,533
878	0	713	713	0	0	0	494
2464	1742	5644	22,381	0	4,965	8014	5120
0	0	0	1960	0	784	784	0
2296	0	2900	7372	0	8,725	0	0
3193	544	1457	755	5	1,246	26,404	15
0	0	1172	2695	0	2,999	761	792
7051	709	9493	12,441	0	5,800	15,465	0
0	190	0	2475	0	2,607	910	1268
							7433
120,476	24,323	54,244	339,136	23,570	231,398	277,155	98,942
7.92	1.60	3.57	22.30	1.55	15.21	18.22	6.51
64,460	53,015	40,804	256,492	NA[g]	186,673	168,677	71,304
5.01	4.12	3.17	19.94	NA	14.52	13.12	5.54

Table 2. Acreage, grain yield, and production of rice in the United States from 2014 to 2016.[a]

State	Area planted			Area harvested			Yield			Production		
	2014	2015	2016	2014	2015	2016	2014	2015	2016	2014	2015	2016
	(1000 acres)						(lb/acre)			(1000 cwt[b])		
Arkansas	1486	1311	1546	1480	1291	1521	7560	7340	6920	111,957	94,710	105,314
California	445	429	541	442	426	536	8580	8890	8840	37,936	37,877	47,394
Louisiana	466	420	437	462	415	428	7130	6940	6630	32,944	28,791	28,390
Mississippi	191	150	195	190	149	194	7420	7110	7180	14,096	10,594	13,929
Missouri	216	182	236	213	174	231	6830	7020	6650	14,540	12,212	15,352
Texas	150	133	195	146	130	187	7360	6900	7360	10,742	8964	13,766
United States	2954	2625	3150	2933	2585	3097	7576	7472	7237	222,215	193,148	224,145

[a] Source: USDA-NASS, 2017.
[b] cwt = hundredweight.

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

	2014		2015		2016	
Cultural practice	**Acreage**	**% of total**	**Acreage**	**% of total**	**Acreage**	**% of total**
Arkansas rice acreage	**1,480,000**	**100.00**	**1,286,000**	**100.00**	**1,521,000**	**100.00**
Soil texture						
Clay	290,508	19.6	264,441	20.6	363,146	23.9
Clay loam	311,721	21.1	268,398	20.9	313,327	20.6
Silt loam	825,486	55.8	689,012	53.6	734,481	48.3
Sandy loam	41,474	2.8	53,116	4.1	96,215	6.3
Sand	10,811	0.7	11,033	0.9	13,703	0.9
Tillage practices						
Conventional	883,586	59.7	818,368	63.6	928,017	61.0
Stale seedbed	482,323	32.6	386,620	30.1	536,682	35.3
No-till	114,090	7.7	81,011	6.3	56,301	3.7
Crop rotations						
Soybean	1,069,283	72.2	930,396	72.3	1,040,054	68.4
Rice	317,662	21.5	273,627	21.3	309,667	20.4
Cotton	4,030	0.3	3,718	0.3	1,908	0.1
Corn	41,093	2.8	42,343	3.3	60,890	4.0
Grain sorghum	11,532	0.8	15,450	1.2	22,621	1.5
Wheat	7,222	0.5	852	0.1	16,864	1.1
Fallow	29,178	2.0	19,613	1.5	65,471	4.3
Other	0	0.0	0	0.0	3,525	0.2
Seeding methods						
Drill seeded	1,250,157	84.5	1,074,460	83.6	1,288,211	84.7
Broadcast seeded	229,843	15.5	211,540	16.4	232,789	15.3
Water seeded	61,221	4.1	70,302	5.5	82,791	5.4
Irrigation water sources						
Groundwater	1,145,847	77.4	982,419	76.4	1,126,578	74.1
Stream, rivers, etc.	155,345	10.5	146,202	11.4	211,537	13.9
Reservoirs	178,807	12.1	157,379	12.2	182,885	12.0
Irrigation methods						
Flood, levees	885,796	59.9	731,614	56.9	942,868	62.0
Flood, multiple inlet	585,658	39.6	521,689	40.6	503,719	33.1
Intermittent (AWD)	--	--	21,241	1.7	33,616	2.2
Furrow	6,203	0.4	11,456	0.9	40,797	2.7
Sprinkler	458	0.0	0	0.0	0	0.0
Other	1,885	0.1	0	0.0	0	0.0
Stubble management						
Burned	414,650	28.0	559,736	43.5	668,592	44.0
Tilled	537,686	36.3	501,329	39.0	666,375	43.8
Rolled	548,333	37.0	343,383	26.7	383,633	25.2
Winter flooded	294,729	19.9	262,846	20.4	330,233	21.7

continued

Table 3. Continued.

	2014		2015		2016	
Cultural practice	**Acreage**	**% of total**	**Acreage**	**% of total**	**Acreage**	**% of total**
Land management						
Contour levees	402,239	27.2	625,600	48.6	703,436	46.2
Precision-level	896,041	60.5	519,907	40.4	607,274	39.9
Zero-grade	181,720	12.3	141,897	11.0	210,290	13.8
Precision agriculture						
Yield monitors	877,850	59.3	847,603	65.9	1,002,492	65.9
Grid sampling	437,759	29.6	386,143	30.0	456,706	30.0
Variable-rate fertilizer	367,045	24.8	336,228	26.1	397,670	26.1
N-STaR	--	--	--	--	165,013	10.8
Pest management						
Insecticide seed treatment	1,047,204	70.8	867,242	67.4	1,154,060	75.9
Fungicide (foliar application)	853,570	57.7	674,727	52.5	833,312	54.8
Insecticide (foliar application)	526,939	35.6	462,302	35.9	623,344	41.0

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

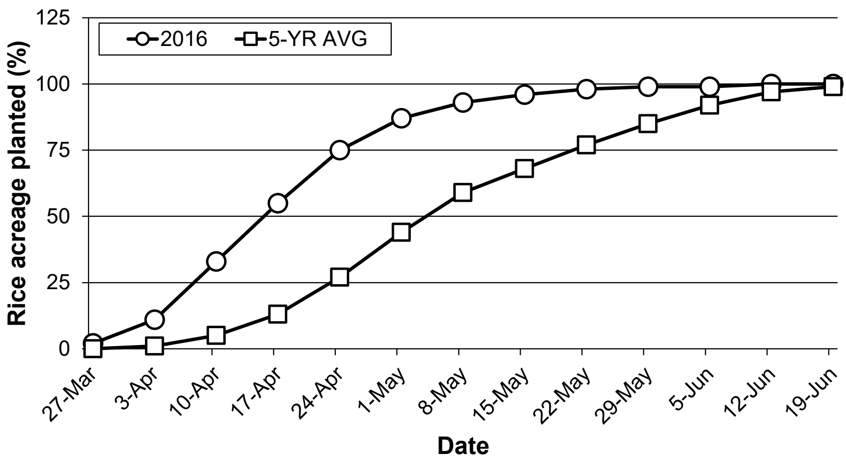

Fig. 1. Arkansas rice planting progress during 2016 compared to the 5-year state average (USDA-NASS, 2017).

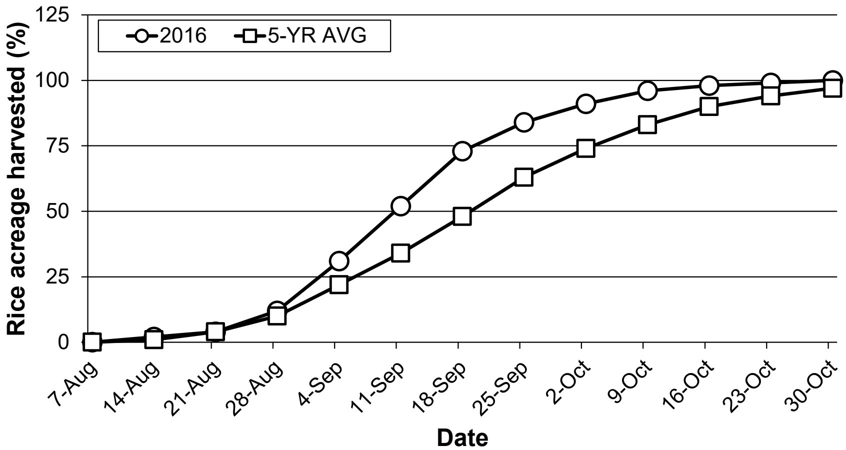

Fig. 2. Arkansas rice harvest progress during 2016 compared to the 5-year state average (NASS, 2017).

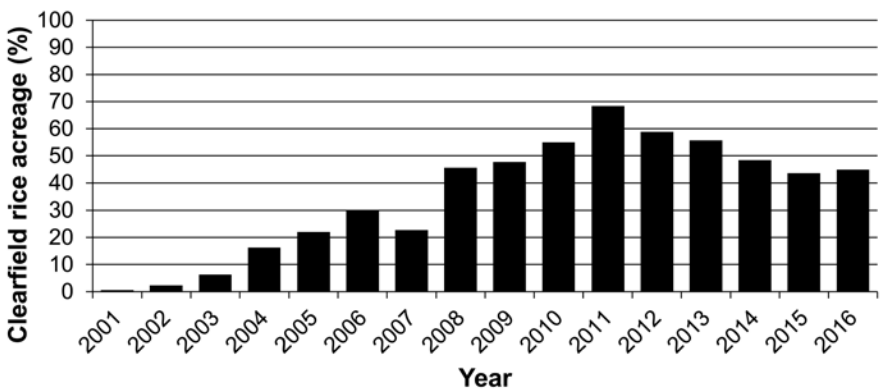

Fig. 3. Percentage of rice planted in Arkansas to Clearfield rice cultivars between 2001 and 2016.

2016 Rice Research Verification Program

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Abstract

The 2016 Rice Research Verification Program (RRVP) was conducted on 15 commercial rice fields across Arkansas. Counties participating in the program included Arkansas, Ashley, Chicot, Clay, Conway, Cross, Desha, Jefferson, Lawrence, Lee, Lincoln, Mississippi, Monroe, Phillips, and White counties for a total of 812 acres. Grain yield in the 2016 RRVP averaged 166 bu/acre ranging from 140 to 236 bu/acre. The 2016 RRVP average yield was 12 bu/acre greater than the estimated Arkansas state average of 154 bu/acre. The highest yielding field was in Chicot County with a grain yield of 236 bu/acre. The lowest yielding field was in Lee County and produced 140 bu/acre. Milling quality in the RRVP was comparable with milling from the Arkansas Rice Performance Trials and averaged 56/69 (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 446 commercial rice fields in 33 rice-producing counties in Arkansas. Since its inception, the program has averaged 19.4 bu/acre better than the state aver-

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age. This increase in yield over the state average can be attributed mainly 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 2016 included Arkansas, Ashley, Chicot, Clay, Conway, Cross, Desha, Jefferson, Lawrence, Lee, Lincoln, Mississippi, Monroe, Phillips, and White Counties. In addition, county agents with rice responsibilities in seven other counties participated in the program training. The Conway County field facilitated training for most of this group.

The 15 rice fields totaled 812 acres enrolled in the program. Seven different cultivars were seeded: CL151, RiceTec CLXL729, RiceTec CLXL745, Diamond, Jupiter, Roy J, and RiceTec XL753. Cooperative Extension Service recommendations were used to manage the RRVP fields. Agronomic and pest management decisions were based on field history, soil-test results, rice cultivar, and data collected from individual fields during the growing season. An integrated pest management philosophy was utilized based on CES recommendations. Data collected included components such as stand density, weed populations, disease infestation levels, insect populations, rainfall, irrigation amounts, dates for specific growth stages, grain yield, milling yield, and grain quality.

Results and Discussion

Yield

The average RRVP yield was 166 bu/acre with a range of 140 to 236 bu/acre (Table 1). All grain yields of RRVP fields are reported in dry bushels (bu) per acre at 12% moisture. The RRVP average was 12 bu/acre more than the estimated Arkansas state average yield of 154 bu/acre. This yield difference, and at times a considerably greater yield 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 Chicot County field, seeded with RiceTec XL745, was the highest yielding RRVP field at 236 bu/acre. Six of the fifteen fields enrolled in the program exceeded 170 bu/acre. Lee County had the lowest yielding field with Roy J producing 140 bu/acre.

Milling data was recorded on all of the RRVP fields. The average milling yield for the fifteen fields was 56-69 (% head rice and % total white rice) with the highest milling yield of 61-72 obtained by RiceTec XL 753 in White County (Table 1). The lowest milling yield was 46-65 obtained by Diamond in Arkansas County. The milling yield of 55-70 is considered the standard used by the rice milling industry.

Planting and Emergence

Planting began with Jefferson County on 29 March and ended with Phillips County on 11 May (Table 1). One of the verification fields was planted in March, twelve in April, and two in May. An average of 75 lb seed/acre was planted for pure-line varieties and 24 lb seed/acre for hybrids. Seeding rates were determined with the CES RICESEED program for all fields. An average of 13 days was required for emergence. Stand density averaged 18 plants/ft^2 for pure-line varieties and 5 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 for all fifteen RRVP fields and reduced the total nitrogen (N)-fertilizer recommendation by an average of 33 lb N/acre when compared with the standard N-fertilizer recommendation. However, various issues unrelated to N-STaR triggered the decision to apply additional N in six fields at some point in the season. The issues prompting these N-fertilizer additions are described in the field reviews and the amounts are included in Table 2.

As with standard N-fertilizer recommendations for rice, N-STaR N recommendations take into account a combination of factors including soil texture, previous crop, and cultivar requirements (Tables 1 and 2).

Phosphorus, potassium, and zinc fertilizer were applied based on soil test analysis recommendations (Table 2). Phosphorus was applied preplant to Arkansas, Chicot, Clay, Cross, Desha, Jefferson, Lawrence, Lee, Monroe and White County fields. Potassium was applied to Arkansas, Clay, Cross, Lee, Monroe and White Counties. Zinc was applied as a preplant fertilizer to fields in Clay, Cross, Desha, Lawrence, Lee, and White Counties, while zinc seed treatment was used with all hybrid rice cultivars at a rate of 0.5 lb zinc/60 lb seed. The average cost of fertilizer across all fields was $86.00.

Weed Control

Command was utilized in all 15 fields for early-season grass control (Table 3). Facet was an active ingredient in multiple products and was applied in 12 of 15 fields in some form either pre-emergence or early post-emergence. Overlapping residuals proved to be an effective strategy utilized in 12 of 15 fields.

Three fields (Ashley, Chicot and Lawrence Counties) were seeded in Clearfield cultivars (Table 1). Of these, only Lawrence utilized Clearfield technology herbicides (Table 3). Two fields, (Clay and Mississippi Counties) did not require a post-emergence herbicide application for grass weed control.

Disease Control

A foliar fungicide was applied in only one of the 15 fields (Desha County). The treatment was for the prevention of kernel smut (Table 4). Generally, fungicide rates are determined based on cultivar, growth stage, climate, disease incidence/severity, and disease history. However, a preventative treatment for kernel smut requires a specific rate depending on the product used. All 15 fields had a seed treatment containing a fungicide.

Insect Control

Seven fields (Arkansas, Ashley, Conway, Desha, Lincoln, Phillips and White Counties) were treated with a foliar insecticide application for rice stink bug (Table 4). Six fields received an insecticide seed treatment with CruiserMaxx Rice and five with NipsIt INSIDE.

Irrigation

Well water was used exclusively for irrigation in 12 of the 15 fields in the 2016 RRVP while 2 fields (Arkansas and White Counties) were irrigated exclusively with surface water and 1 field (Conway County) used both well and surface water. Three fields (Arkansas, Chicot, and Conway Counties) were zero-grade. Two fields (Jefferson and Lincoln Counties) were row watered/furrow irrigated. Multiple-Inlet Rice Irrigation (MIRI) was utilized in 12 fields either by irrigating with 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 8 of the fields to record water usage throughout the growing season (Table 5). In fields where flow meters for various reasons could not be 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 a low of 10.00 inches to a high of 22.25 inches.

Economic Analysis

This section provides information on production costs and returns for the 2016 Rice Research Verification Program (RRVP). Records of field operations on each field provided the basis for estimating production costs. The field records were compiled by the RRVP coordinators, county Extension agents, and cooperators. Production data from the 15 fields were applied to determine costs and returns above operating costs, as well as total specified costs. Operating costs and total costs per bushel of rice 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 2016 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 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 $384.87/acre for Phillips County to $635.31 for Chicot County, while operating costs per bushel ranged from $2.60/bu for Phillips County to $3.81/bu for Jefferson County. Total costs per acre (operating plus fixed) ranged from $487.65/acre for Phillips County to $721.94/acre for Chicot County, and total costs per bushel ranged from $3.06/bu for Chicot County to $4.32/bu for Jefferson County. Returns above operating costs ranged from $142.58/acre for Clay County to $456.96/acre for Chicot County, and returns above total costs ranged from $50.14/acre for Clay County to $370.33/acre for Chicot County.

A summary of yield, rice price, revenues, and expenses by expense type for each RRVP field is presented in Table 7. The average rice yield for the 2016 RRVP was 166 bu/acre but ranged from 140 bu/acre for Lee County to 236 bu/acre for Chicot County. An Arkansas average long-grain cash price of $4.56/bu and an Arkansas average medium-grain cash price of $4.49/bu were estimated using USDA, National Agricultural Statistics Service (USDA-NASS, 2017) U.S. long- and medium-grain price data for the months of August through October. The RRVP had one field planted to a medium-grain cultivar (Monroe County). 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 65% of whole grain price value. If milling yield was higher than the standard, a premium was made while a discount was given for milling less than the standard. Estimated long-grain prices adjusted for milling yield varied from $4.11/bu in Arkansas County to $4.79/bu in White County. The medium-grain price adjusted for milling yield for the Monroe County field was $4.38/bu (Table 7).

The average operating expense for the 15 RRVP fields was $513.75/acre (Table 7). Post-harvest expenses accounted for the largest share of operating expenses on average (21.4%) followed by seed (19.6%), fertilizers and nutrients (16.7%), and chemicals (14.0%). Although seed's share of operating expenses was 19.6% across the 15 fields, its' average cost and share of operating expenses varied depending on whether a Clearfield hybrid was used ($152.24/acre; 25.5% of operating expenses), a non-Clearfield hybrid was used ($132.97/acre; 23.7% of operating expenses), a Clearfield non-hybrid (pure-line) variety was used ($88.50/acre; 18.5% of operating expenses) or a non-Clearfield non-hybrid (pure-line) variety was used ($52.59/acre; 11.8% of operating expenses).

The average return above operating expenses for the 15 fields was $237.02/acre and ranged from $142.58/acre for Clay County to $456.96/acre for Chicot County (Table 7). The average return above total specified expenses for the 15 fields was $146.61/acre and ranged from $50.14/acre for Clay County to $370.33/acre for Chicot County. Table 8 provides select variable input costs for each field and includes a further breakdown of chemical costs into herbicides, insecticides, and fungicides. Table 8 also lists the specific rice cultivars grown on each RRVP field.

Field Summaries

Arkansas County

The zero-grade Arkansas County field was located between Hagler and Bayou Meto on a Dewitt silt loam soil. The field consisted of 20 acres and the previous crop grown on the field was soybean. Diamond, a new variety released from the University of Arkansas System Division of Agriculture, was treated with CruiserMaxx Rice seed treatment and drill seeded. The seeding rate was 75 lb/acre planted on 9 April. Emergence was observed on 18 April with a stand count of 18 plants ft^2. Conventional tillage practices were used for field preparation in the spring. According to the soil-test recommendation, a 0-30-90 (lb/acre N-P_2O_5-K_2O, respectively) mixed fertilizer was applied. Command and League herbicides were applied at planting on 9 April. Facet was applied as a pre- and post-emergence herbicide on 11 May. Using the N-STaR recommendation, N fertilizer in the form of urea plus an approved N-(n-butyl) thiophosphoric triamide (NBPT) product were applied at a rate of 225 lb/acre on 12 May. Midseason N was applied as urea on 29 June at a rate of 80 lb/acre. An adequate flood was maintained throughout the growing season. Rice stink bugs reached threshold levels and Mustang Max insecticide was applied on 20 July. No fungicide treatment was necessary for disease control. The rice was harvested on 30 August with a yield of 154 bu/acre and a milling yield of 46-65 (% head rice and % total rice). A prolonged period of high nighttime temperatures that reached or exceeded 75 °F at early heading resulted in considerable blanking. Excessive rainfall at harvest caused standing rice to sprout in the heads and false smut and sooty mold to be prevalent. The average harvest moisture was 13%. Total irrigation was 30 acre-inches with a season rainfall total of 14.6 inches.

Ashley County

The 38-acre contoured field in Ashley County was located just south of Portland on Grubbs silt loam and Jackport silty clay loam soils. Conventional tillage practices were utilized and the previous crop was soybean. The variety was RiceTec hybrid CLXL729 treated with the company's standard seed treatment. The field was drill-seeded on 26 April at a rate of 26 lb/acre. Emergence was observed on 10 May with a stand count of 6 plants/ft^2. Glyphosate, Command, and League herbicides were applied for burndown and pre-emergence weed control on 26 April. There was a long delay establishing the contour levees, yet pre-emergence herbicides coupled with rainfall gave extended control. Facet and Permit Plus were applied as post-emergence herbicides on 26 May. Nitrogen fertilizer in the form of urea with an approved NBPT product were applied on 2 June at a rate of 260 lb/acre according to the N-STaR recommendation. An adequate flood was maintained throughout the growing season. The late boot application of urea was applied on 2 July at 70 lb/acre. No fungicides were necessary for disease control. Rice stink bug reached threshold levels and Lambda-Cy insecticide was applied on 28 July. The field was harvested on 28 September and had a yield of 173 bu/acre, an average harvest moisture of 18%, and a milling yield of 58-68. The irrigation water use totaled 30 acre-inches and the rainfall for the growing season was 11 inches.

Chicot County

The 69-acre zero-grade Chicot County field was located north of Lake Village on a Perry clay soil. On 26 April, RiceTec hybrid CLXL745, treated with the company's standard seed treatment, was drill-seeded at 24 lb/acre. Glyphosate, Command, and Sharpen herbicides were applied on 4 April for burndown and pre-emergence weed control. Field emergence was recorded on 15 May with a stand density of 2 plants/ft^2 that eventually increased to 2.5 plants/ft^2. On 7 June Ricestar HT and Command were applied as pre- and post-emergence herbicides which was followed by an application of RiceBeaux. Based on N-STaR recommendations, N fertilizer in the form of urea with an approved NBPT product were applied at 200 lb/acre on 12 June. An adequate flood was maintained throughout the growing season. Urea fertilizer was applied at late boot on 21 July at 70 lb/acre. No fungicides or insecticides were necessary for the growing season. The field was harvested 9 September with a yield of 236 bu/acre, a milling yield of 58-70, and an average harvest moisture of 14%. This field had the highest yield in the 2016 Rice Research Verification program. The grower was very pleased with the yield considering the low stand count and excessive rainfall at harvest time. The irrigation amount was 30.0 acre-inches and the rainfall amount was 18.6 inches for the growing season.

Clay County

The precision-graded Clay County field was located northeast of Piggott on a Fountain silt loam soil. The field was 90 acres and the previous crop grown on the field was soybean. Conventional tillage practices were used for field preparation in the fall and a pre-plant fertilizer based on soil test analysis was applied pre-plant in the spring at a rate of 0-20-80-10 (lb/acre N-P_2O_5-K_2O-Zn, respectively). A burndown herbicide tank mix of Roundup plus Sharpen was applied pre-plant. RiceTec hybrid XL753, with the company's standard seed treatment plus NipsIt INSIDE insecticide seed treatment, was drill-seeded at a rate of 24 lb/acre on 15 April. Rice emergence was observed on 28 April with a stand count of 6 plants/ft^2. Command and Facet L herbicides were applied pre-emergence providing excellent weed control. No post-emergence herbicide application was needed. Off-target herbicide drift combined with unfavorably cool weather reduced the seedling stand to 4 plants/ft^2. Ammonium sulfate was applied at 100 lb/acre to stimulate growth and recovery. Using the N-STaR recommendation, urea plus an approved NBPT product were applied preflood on 2 June at a rate of 220 lb/acre. Multiple-inlet irrigation was utilized to achieve a more efficient permanent flood. Even so, the permeable nature of the soil made flood levels somewhat difficult to maintain during the season. A late boot application of urea was made at a rate of 65 lb/acre. No insecticide or fungicide treatments were required for pest control. The rice was harvested on 30 August with a yield of 154 dry bu/acre, a milling yield of 58-70, and an average harvest moisture of 16.3%. Total irrigation for the season was 39.7 acre-inches and rainfall was 15.4 inches.

Conway County

The zero-grade Conway County field was southeast of Blackwell on a Dardanelle silt loam. The field was 51.5 acres and the previous crop grown on the field was soybean. Conventional tillage practices were used for field preparation in the spring and based on soil test analysis, no pre-plant fertilizer was applied. A burndown/pre-emergence herbicide tank mix of generic glyphosate plus Command was applied at planting. Rice Tec hybrid XL753 with the company's standard seed treatment plus NipsIt INSIDE insecticide seed treatment was drill-seeded at a rate of 23 lb/acre on 15 April. Rice emergence was observed on 24 April with a stand count of 5 plants/ft^2. Ammonium sulfate was applied at 100 lb/acre due to the somewhat thin stand and to stimulate recovery from cool weather. A post-emergence application of RiceBeaux herbicide was made on 12 May providing good control of weeds except for some small, scattered patches of red rice that required manual control. Using the N-STaR recommendation, urea plus an approved NBPT product were applied preflood on 18 May at a rate of 155 lb/acre. A permanent flood was established with a cascade system primarily using an electric well, but river water from the local Irrigation District was also utilized. Flood levels were maintained well throughout the season. A late boot application of urea was made at a rate of 65 lb/acre. Rice stink bug moved into the field at extremely high numbers and were treated with Lambda-Cy on 12 July followed by a second treatment a week later. No fungicide treatments were required. The rice was harvested on 31 August yielding 176 bu/acre. The milling yield was 56-70 and the average harvest moisture was 11.7%. Total irrigation for the season was 16.8 acre-inches and rainfall was 12.4 inches.

Cross County

The traditionally contoured Cross County field was located southwest of Hickory Ridge on Crowley and Hillemann silt loam soils. The field was 98 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 the rate of 0-50-90-5 (lb/acre N-P_2O_5-K_2O-Zn, respectively). On 7 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 20 April and consisted of 20 plants/ft^2. Command herbicide was applied pre-emergence followed by a post-emergence tank mix application of Obey and Permit Plus. Excellent pre- and post-emergence control of weeds was achieved. Using the N-STaR recommendation, urea plus an approved NBPT product were applied preflood on 26 May at the rate 220 lb/acre. Application streaking of the N occurred in part of the field and had to be corrected with an additional 75 lb/acre of urea on 25 acres. Multiple risers were utilized to achieve a more efficient permanent flood. Once the permanent flood was established, flood levels were maintained adequately throughout the season. A midseason application of urea was made at a rate of 100 lb/acre. No fungicide or insecticide applications were required. The rice was harvested on 15 September yielding 158 bu/acre. This lower than expected yield was attributed primarily to considerable blanking due to adverse weather during the pollination period. The milling yield was 52-70 and the average harvest moisture was 12%. Total irrigation was 20.5 acre-inches and total rainfall for the season was 14.6 inches.

Desha County

The Desha County 50-acre contour-levee field was located just south of Dumas on Herbert silt loam and Perry clay soils. Traditional tillage practices were performed and the previous crop was soybean. According to the soil-test recommendation, the preplant fertilizer 0-46-0-4 (lb/acre N-P_2O_5-K_2O-Zn, respectively) was applied in the spring. Roy J treated with NipsIt Suite Rice insecticide seed treatment was drill-seeded at 70 lb/ acre on 6 April. Command and League herbicides were applied on 6 April for pre-emergence weed control. Emergence was observed on 21 April with 19 plants/ft^2. Facet was applied as a post-emergence herbicide on 12 May. Nitrogen fertilizer in the form of urea plus an approved NBPT product were applied at 260 lb/acre on 18 May according to the N-STaR recommendation. Midseason urea was applied at 100 lb/acre on 8 June according to GreenSeeker recommendation. The field had a history of kernel smut and rice stink bugs reached treatment threshold levels. Stratego fungicide and Lambda-Cy insecticide were applied on 19 July. The field was harvested on 31 August yielding 151 bu/acre with a milling yield of 51-69, and an average harvest moisture of 17%. Considerable blanking was observed and rice sprouting was prevalent from excessive rainfall and high humidity at harvest. The irrigation amount was 30 acre-inches and the total rainfall amount was 22.3 inches.

Jefferson County

The Jefferson County 67-acre row water/furrow irrigated field was located 10 miles south of Pine Bluff on the Arkansas River. The soil series was a Rilla silty clay loam soil and the previous crop was soybean. The RiceTec hybrid XL753 treated with the company's standard seed treatment was drill-seeded at 24 lb/acre on 29 March. A preplant fertilizer based on soil test analysis was applied on 30 March at a recommended rate of 0-50-0 (lb/acre of N-P_2O_5-K_2O, respectively). Touchdown, Command, and League herbicides were applied on 8 April for burndown and pre-emergence grass, broadleaf, and aquatic weed control. Rice emergence was observed on 15 April with a stand density of 6 plants ft^2. Prowl and Facet pre-emergence herbicides were applied on 2 May. Using the N-STaR recommendation, N fertilizer in the form of urea with an approved NBPT product were applied at 325 lb/acre on 9 May. Intermittent flushing was utilized every 2 to 3 days as row water irrigation. A second urea application was made on 19 May at 100 lb/acre to compensate for N loss due to the row water irrigation. Midseason urea was applied on 31 May at 70 lb/acre. No fungicides or insecticides were warranted during the growing season. Sodium chlorate was applied on 27 August as a desiccant on vegetative growth to the lower one-third of the field. The field was harvested on 29 August with a yield of 165 bu/acre, a milling yield of 63-69, and an average harvest moisture of 14%. The irrigation amount was 30 acre-inches and the rainfall amount totaled 18.5 inches.

Lawrence County

The precision-grade 50-acre Lawrence County field was located north of Alicia on a Jackport silty clay loam soil. The previous crop grown on the field was soybean. Conventional tillage practices were used for field preparation in the spring. A preplant fertilizer based on soil test analysis was applied on 13 April at the recommended rate of 0-68-0-2 (lb/acre of N-P_2O_5-K_2O-Zn, respectively). On 14 April, the variety CL151 treated with CruiserMaxx Rice was drill-seeded at a rate of 74 lb/acre. Emergence was observed on 29 April with a stand count of 13 plants/ft^2. RoundUp tank-mixed with Command was applied as a burndown/pre-emergence herbicide treatment on 18 April. This was followed on 7 May by a post-emergence herbicide tank mix of Newpath plus Strada. A second post-emergence application on 11 June included Clearpath and Permit Plus. Very good pre- and post-emergence control of weeds was achieved. Using the N-STaR recommendation, urea plus an approved NBPT product were applied at 175 lb/acre in a single preflood application. 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. A corrective urea application of 75 lb/acre was required during late midseason. No fungicide or insecticide applications were required. On 2 September, sodium chlorate was applied as a harvest aid treatment. The field was harvested on 7 September with a grain yield of 176 bu/acre, a milling yield of 56-68, and an average harvest moisture of 16.8%. Total irrigation for the season was 15.9 acre-inches and rainfall was 15.9 inches.

Lee County

The Lee County 37-acre field was located just east of Moro on a Calloway and Henry silt loam soil. Soybean was the previous crop grown on the field. Conventional tillage practices were performed on the contour-levee field. A preplant fertilizer blend of 0-30-60-11 (lb/acre N-P_2O_5-K_2O-Zn, respectively) was applied according to the soil sample analysis. On 26 April the variety Roy J, treated with CruiserMaxx Rice seed treatment plus zinc, was drill-seeded at a rate of 75 lb/acre. Sharpen and Command were applied on 26 April as burndown and pre-emergence herbicides. Emergence was observed on 10 May with 17 plants/ft^2. Facet L was applied on 24 May as a post-emergence herbicide. Based on N-STaR recommendations, N fertilizer in the form of urea plus an approved NBPT product were applied at 250 lb/acre on 2 June. A minimal flood was maintained throughout the growing season with multiple-inlet irrigation. Using GreenSeeker (Trimble Navigation Limited, Sunnyvale, Calif.) recommendation, no midseason urea fertilizer was necessary. Numerous hybrid off-types were observed late season. The field was harvested on 8 September with a yield of 140 bu/acre, a milling yield of 59-68, and an average harvest moisture of 15%. The irrigation water use totaled 55.5 acre-inches and the season-long rainfall total was 12.0 inches.

Lincoln County

The Lincoln County 31-acre row water/furrow-irrigated field was located just south of Grady on a Perry clay soil. The previous crop was corn and there were no spring tillage practices performed. Afforia, 2,4-D, and Select herbicides were applied in early spring for burndown and winter annual grass and weed control. Based on soil test analysis, no preplant fertilizer was needed. RiceTec hybrid XL753 treated with Cruiser-Maxx Rice in addition to the company's standard seed treatment was drill-seeded on 9 April at a rate of 24 lb/acre. The rice emerged on 20 April at 5 plants/ft^2. Command, League, Firstshot and glyphosate herbicides were applied on 9 April for burndown and pre-emergence weed control. Prowl herbicide was applied on 28 April to aid in grass residual control. Facet and Permit were applied as post-emergence herbicides on 9 May. Using the N-STaR recommendation, N fertilizer in the form of urea plus an approved NBPT product were applied at 300 lb/acre on 10 May. A second application of urea was made on 7 June at 100 lb/acre to compensate for N loss due to row water irrigation. The late boot urea application was applied on 10 July at 70 lb/acre. Rice stink bug reached threshold levels prompting Mustang Maxx to be applied on 12 July. The field was harvested on 23 August with a yield of 173 bu/acre, a milling yield of 53-70, and an average harvest moisture of 15%. The irrigation water use was 48 acre-inches and the rainfall totaled 15.1 inches.

Mississippi County

The precision-grade Mississippi County field was located west of Wilson on a Sharkey and Tunica silty clay soil and the previous crop was soybean. The field was 68 acres and conventional tillage practices were used for field preparation in the spring. A tank mix of glyphosate plus 2,4-D was applied as an early spring burndown herbicide. Based on soil test analysis, no preplant fertilizer was needed. RiceTec hybrid XL753 with the company's standard seed treatment was drill-seeded at a rate of 24 lb/acre on 9 April. Rice emergence was observed on 22 April with a stand count of 10 plants/ft^2. However, herbicide injury reduced the stand to 7 plants/ft^2. Ammonium sulfate at 75 lb/acre plus urea at 75 lb/acre[3] was applied to stimulate growth and recovery. Command plus Facet L herbicides were applied at planting and provided excellent weed control. No post-emergence herbicide application was needed. Urea plus an approved NBPT product at a rate of 240 lb/acre were applied preflood on 24 May. Multiple-inlet irrigation was utilized to achieve a more efficient permanent flood. Once the permanent flood was established, flood levels were maintained well throughout the season. Harvest began on 1 September and the field yielded an average of 187 bu/acre. Moisture at harvest was 14% and the milling yield was 63-69. Total irrigation was 20.7 acre-inches and total rainfall was 13.8 inches.

Monroe County

The Monroe County straight-levee 70-acre 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, mixed fertilizer at the rate of 0-60-60 (lb/acre N-P_2O_5-K_2O, respectively) was applied in the spring. The medium-grain variety Jupiter, treated with CruiserMaxx Rice and Release seed treatments, was drill-seeded at 65 lb/acre on 9 April. Emergence was observed on 26 April at 16 plants/ft^2. Glyphosate, Command, and League herbicides were applied on 10 April. Prowl herbicide was applied pre-emergence on 9 May. Facet and Permit Plus were applied 17 May as post-emergence herbicides. Nitrogen fertilizer in the form of urea plus an approved NBPT product were applied 12 June at 180 lb/acre according to the N-STaR recommendation. An adequate permanent flood was maintained throughout the growing season using multiple-inlet irrigation. Areas of ALS resistant annual sedge were observed throughout the growing season. No fungicide or insecticide applications were necessary due to careful scouting. Midseason N as urea was applied at 100 lb/acre on 2 July according to GreenSeeker recommendation. Sodium chlorate was applied on 28 August as a desiccant. The field was harvested 31 August with a yield of 142 bu/acre and a milling yield of 55-68. Irrigation totaled 20.0 acre-inches and rainfall amounts totaled 16.4 inches.

Phillips County

The contoured Phillips County 38-acre field was located north of Wabash on Tunica silty clay soil. Conventional tillage was used after the previous soybean crop.

[3] Though recommended in certain situations, the addition of urea to ammonium sulfate was a miscommunication rather than a recommendation in this case. Either product in the amount applied would have sufficed without the other to meet the need.

Based on soil test analysis, no preplant fertilizer was needed. The variety Roy J was treated with NipsIt Suite Rice seed treatment and drill-seeded at 75 lb/acre on 11 April. Emergence was observed on 28 April at 22 plants/ft^2. Facet L and Command were applied as pre-emergence herbicides on 12 May. Facet L was applied on 7 June as a post-emergence herbicide. Nitrogen in the form of urea plus an approved NBPT product were applied on 8 June at 175 lb/acre. Multiple-inlet irrigation was utilized to achieve a more efficient permanent flood. Midseason N was applied as urea at 100 lb/acre on 13 July according to GreenSeeker recommendation. Rice stink bugs reached threshold levels and Lambda-Cy insecticide was applied 13 July. The field was harvested on 28 September yielding 148 bu/acre with a milling yield of 51-65. The irrigation amount was 30 acre-inches and the rainfall amount was 10.0 inches.

White County

The precision-grade White County field was located south of Kensett on Calhoun and Calloway silt loam soils. The field was 34.7 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 0-50-50-10 (lb/acre N-P_20_5-K_20-Zn, respectively) on the north 18 acres. This portion of the field has not performed as well as the remainder of the field ever since it had a land leveling correction a few years ago. No preplant fertilizer was required on the remainder of the field. On 8 May, RiceTec hybrid XL753 with the company's standard seed treatment plus NipsIt INSIDE insecticide was drill-seeded at a rate of 22 lb/acre. Rice emergence was observed on 15 May and consisted of 7 plants/ft^2. Command herbicide was applied pre-emergence followed by a post-emergence application of propanil providing excellent control of weeds. Using the N-STaR recommendation, urea plus an approved NBPT product were applied preflood at a rate of 200 lb/acre on 17 June. Once the permanent flood was established, flood levels were maintained well throughout the season. However, N deficiency symptoms began to appear on the north 18 acres making it necessary to apply additional N to correct the problem. Urea at a rate of 85 lb/acre was applied. The entire field received the normal 65 lb/acre of urea at late boot. Based on field evaluations, no fungicide application was required. Rice stink bugs exceeded the threshold for treatment on the north 18 acres which was about a week behind the rest of the field. Control was achieved with a single application of Lamda-Cy on 7 September. The field was harvested on 20 September yielding a disappointing 156 bu/acre due in part to excessive rains during flowering. Moisture at harvest was 15.9% and the milling yield was 61-72. Total irrigation was 12.1 acre-inches and total rainfall for the season was 20.2 inches.

Significance of Findings

Data collected from the 2016 RRVP reflects the general trend of decreasing rice yields and average returns in the 2016 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 2016 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/ft²)					(bu/acre)		(%)
Arkansas	Diamond	20	Soybean	75	18	09-Apr	18-Apr	30-Aug	154	46/65	13
Ashley	CLXL729	38	Soybean	26	6	26-Apr	10-May	7-Sep	173	58/68	14
Chicot	CLXL745	69	Rice	24	2.5	26-Apr	15-May	8-Sep	236	58/70	14
Clay	XL753	90	Soybean	24	4	15-Apr	28-Apr	30-Aug	154	58/70	16.3
Conway	XL753	51.5	Rice	23	5	13-Apr	24-Apr	31-Aug	176	56/70	11.7
Cross	Roy J	98	Soybean	90	20	07-Apr	20-Apr	15-Sep	158	52/70	12
Desha	Roy J	50	Soybean	70	19	06-Apr	21-Apr	31-Aug	151	51/69	17
Jefferson	XL753	67	Soybean	24	6	29-Mar	15-Apr	21-Aug	165	63/69	14
Lawrence	CL151	50	Soybean	74	13	14-Apr	29-Apr	07-Sep	176	56/68	16.8
Lee	Roy J	37	Soybean	75	17	26-Apr	10-May	08-Sep	140	59/68	14.5
Lincoln	XL753	31	Corn	24	5	09-Apr	20-Apr	23-Aug	173	53/70	15
Mississippi	XL753	68	Soybean	24	7	09-Apr	22-Apr	01-Sep	187	63/69	14
Monroe	Jupiter	70	Soybean	65	16	16-Apr	26-Apr	26-Sep	142	55/68	15
Phillips	Roy J	38	Rice	75	22	11-May	28-May	28-Sep	148	51/65	16.3
White	XL753	34.7	Soybean	22	7	8-May	15-May	22-Sep	156	61/72	15.9
Average		54.1		[b]	[c]	17-Apr	30-Apr	6-Sep	166	56/69	14.63

[a] Milling yield = % head rice and % total rice.
[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 2016 Rice Research Verification Program.

Field location by county	pH	Soil test P[a]	Soil test K[a]	Soil test Zn[a]	Applied fertilizer: Mixed fertilizer[b] N-P-K-Zn	Applied fertilizer: N-Star urea (46% N) rates and timing[c,d]	Applied fertilizer: Total N rate[e]	Soil classification
		---------(lb/acre)--------			--------------(lb/acre) -------------		(lb N/acre)	
Arkansas	6.1	54	151	9.1	0-30-90-0	225-80-0	140	Dewitt silt loam
Ashley	6.2	57	340	4.0	0-0-0-0	260-0-70	152	Grubbs silt loam and Jackport silty clay loam
Chicot	7.0	32	788	5.0	18-46-0-0	200-0-70	124	Perry Clay
Clay	6.9	61	175	14.3	21-20-80-10	220-0-65	131	Fountain silt loam
Conway	6.2	96	430	9.6	21-0-0-0	155-0-65	101	Dardanelle silt loam
Cross	7.1	37	169	4.8	0-50-90-5	220-100-0	156†	Crowley and Hillemann silt loams
Desha	7.6	50	359	4.9	0-46-0-4	260-0-0	167†	Perry Clay and Herbert silt loam
Jefferson	7.1	47	506	7.2	0-50-0-0	325-0-70	228†	Rilla silty clay loam
Lawrence	7.3	14	383	3.9	0-68-0-2	175-0-0	115†	Jackport silty clay loam-clay
Lee	7.5	50	197	6.4	0-30-60-11	250-0-0	115	Calloway and Henry silt loam
Lincoln	7.0	89	707	6.9	0-0-0-0	300-0-70	216†	Perry clay
Mississippi	7.1	58	389	5.6	51-0-0-0	240-0-65	140	Sharkey & Tunica silty clays
Monroe	7.0	30	235	4.6	0-60-60-0	180-100-0	129	Grubbs silt loam and Jackport silty clay loam
Phillips	6.3	86	459	5.0	0-0-0-0	175-100-0	127	Tunica silty clay
White N[f]	5.4	46	392	3	0-50-50-10	200-0-65	161†	Calhoun and Calloway silt loams
White S[f]	5.7	61	296	3.9	0-0-0-0	200-0-65	122	Calhoun and Calloway silt loams

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

[b] Column includes seed treatments, regular preplant applications and applications for problems other than nitrogen depletion (details in field reviews). N-P_2O_5-K_2O-Zn-S (includes seed treatments and preplant applications).

[c] Timing: preflood – midseason – boot. All fields were fertilized according to N-STaR recommendations listed in this column.

[d] The N-STaR preflood N was treated with an approved NBPT product to minimize N loss due to ammonia volatilization.

[e] Some fields required more seasonal N than N-STaR recommended in order to counteract N depletion (details in field reviews). This additional N is included in the totals marked (†). Extra N applied 2 weeks or more before flood-up to address other problems is recorded in the "Mixed Fertilizer" column.

[f] North and South are different areas of the same field requiring significantly different fertilizer applications.

Table 3. Herbicide rates and timings for fields enrolled in the 2016 Rice Research Verification Program.

Field location by county	Pre-emergence herbicide applications	Post-emergence herbicide applications
	(trade name and product rate/acre)[a]	
Arkansas	Command (12.8 oz) + League (4 oz)	Facet L (25 oz)
Ashley	Command (16 oz) + League (3.2 oz) + glyphosate (32 oz)	Facet L (32 oz) + Permit Plus (0.75 oz) + COC[d] (1 qt)
Chicot	Command (16 oz) + glyphosate (32 oz) + Sharpen (2 oz)	Ricestar (24 oz) + Command (11 oz) fb[b] RiceBeaux (3 qt)
Clay	Spring Burndown: RoundUp (28 oz) + Sharpen (2 oz) + MSO[c] (12 oz)	None
	Pre-emergence application: Command (12.8 oz) + Facet L (22 oz)	None
Conway	Command (16 oz) + glyphosate (32 oz)	RiceBeaux (4 qt)
Cross	Command (12.8 oz)	Obey (22 oz) + Permit Plus (0.75 oz)
Desha	Command (16 oz) + League (3.2 oz)	Facet (0.5 lb) + COC (12.8 oz)
Jefferson	Command (16 oz) + League (4 oz) + glyphosate (32 oz)	Prowl H_2O (2.1 pt) + Facet (32 oz) + COC (1 qt)
Lawrence	Command (12.8 oz) + glyphosate (42 oz)	Newpath (4 oz) + Strada (2 oz) fb Clearpath (0.5 lb) + Permit (0.75 oz)
Lee	Command (12.8 oz) + Sharpen (2 oz)	Facet L (26 oz)
Lincoln	Spring Burndown: Afforia (2.5 oz) + 2,4-D (16 oz) + Select (12 oz) glyphosate (26 oz) + Firstshot (0.6 oz) + Command (21 oz) + League (4 oz)	Prowl H_2O (2.1 pt) fb Facet L (32 oz) + Permit (1 oz) +COC (1 qt)
Mississippi	Spring Burndown: glyphosate (32 oz) + 2,4-D (16 oz) Command (17.6 oz) + Facet L (30 oz)	None
Monroe	Command (12.8 oz) + League (6.4 oz) + glyphosate (32 oz)	Prowl H_2O (2.1 pt) fb Facet L (25 oz) + Permit Plus (0.75 oz) + COC (1 qt)
Phillips	Command (16 oz) + Facet L (16 oz)	Facet L (25 oz)
White	Command (17.6 oz)	Propanil (3 qt)

[a] All rates specified are on a per-acre basis.
[b] The abbreviation ‘fb’ = followed by and is used to separate herbicide application events.
[c] MSO = methylated seed oil.
[d] COC = crop oil concentrate.

Table 4. Seed treatments used and foliar fungicide and insecticide applications made on fields enrolled in the 2016 Rice Research Verification Program.

Field location by county	Seed treatments: Fungicide and/or Insecticide seed treatment for control of diseases and insects attacking seedling rice	Foliar fungicide and insecticide treatments: 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	CruiserMaxx Rice (7 fl oz)	------	------	------	Mustang Max (3.6 oz)
Ashley	RTST[a]	------	------	------	Lambda-Cy (2.5 oz)
Chicot	RTST	------	------	------	------
Clay	RTST + NipsIt INSIDE	------	------	------	------
Conway	RTST + NipsIt INSIDE	------	------	------	Lambda-Cy (3.6 oz) fb
Lambda-Cy (3.2 oz)					
Cross	CruiserMaxx Rice (7 fl oz)	------	------	------	------
Desha	NipsIt Suite Rice (2.9 fl oz)	Stratego (19 oz)	------	------	Lambda-Cy (4.2 oz)
Jefferson	RTST	------	------	------	------
Lawrence	CruiserMaxx Rice (7 fl oz)		------	------	------
Lee	CruiserMaxx Rice (7 fl oz)	------	------	------	------
Lincoln	CruiserMaxx Rice (7 fl oz)	------	------	------	Mustang Max (4 oz)
Mississippi	RTST	------	------	------	------
Monroe	CruiserMaxx Rice (7 fl oz) +				
Release (0.3 oz)	------	------	------	------	
Phillips	NipsIt Suite Rice (2.9 fl oz)	------	------	------	Lambda-Cy (3.2 oz)
White North	RTST + NipsIt INSIDE	------	------	------	Lambda-Cy (3.2 oz)
White South	RTST + NipsIt INSIDE	------	------	------	------

[a] RTST refers to RiceTec Seed Treatment. This abbreviation and RTST + NipsIt INSIDE defines those fields whose seed was treated by RiceTec, Inc. prior to seed purchase. RTST seed is treated with compounds intended to enhance germination and early-season plant growth while RTST + NipsIt INSIDE includes all the components of RTST plus an insecticide to further protect seedlings.

Table 5. Rainfall and irrigation information for fields enrolled in the 2016 Rice Research Verification Program.

Field location by county	Rainfall	Irrigation[a]	Rainfall + Irrigation
	(inches)	(acre-inches)	(inches)
Arkansas	14.6	30.0*	44.6
Ashley	11.0	30.0*	41.0
Chicot	18.6	30.0*	48.6
Clay	15.4	39.7	55.1
Conway	12.4	16.8	29.2
Cross	14.6	20.5	35.1
Desha	22.3	30.0*	52.3
Jefferson	18.5	30.0*	48.5
Lawrence	15.9	15.9	31.8
Lee	12.0	55.5	67.5
Lincoln	15.1	48.0	63.1
Mississippi	13.8	20.7	34.5
Monroe	16.4	20.0	36.4
Phillips	10.0	30.0*	40.0
White	20.2	12.1	32.3
Average[b]	15.4	27.7†	42.8†

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

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

Table 6. Operating costs, total costs, and returns for fields enrolled in the 2016 Rice Research Verification Program.

County	Operating costs Per acre	Operating costs Per bushel	Returns above operating costs	Fixed costs	Total costs	Returns above total costs	Total costs
	($/acre)	($/bu)	---------------	--------------- ($/acre)	---------------	---------------	($/bu)
Arkansas	433.79	2.82	198.71	70.08	503.87	128.63	3.27
Ashley	558.82	3.23	225.95	94.52	653.33	131.43	3.78
Chicot	635.31	2.69	456.96	86.63	721.94	370.33	3.06
Clay	570.17	3.70	142.58	92.44	662.61	50.14	4.30
Conway	511.28	2.91	294.75	81.07	592.35	213.69	3.37
Cross	465.97	2.95	242.30	100.74	566.71	141.56	3.59
Desha	456.82	3.03	209.46	91.90	548.73	117.56	3.63
Jefferson	628.96	3.81	147.12	84.10	713.06	63.02	4.32
Lawrence	478.59	2.72	311.25	90.31	568.90	220.94	3.23
Lee	451.55	3.23	186.92	110.97	562.52	75.95	4.02
Lincoln	623.20	3.60	156.51	92.11	715.30	64.41	4.13
Mississippi	514.51	2.75	365.05	88.68	603.18	276.37	3.23
Monroe	477.70	3.36	143.91	85.73	563.43	58.17	3.97
Phillips	384.87	2.60	240.93	102.79	487.65	138.15	3.29
White	514.77	3.30	232.94	84.19	598.96	148.75	3.84
Average	513.75	3.11	237.02	90.42	604.17	146.61	3.67

Table 7. Summary of revenue and expenses per acre for fields enrolled in the 2016 Rice Research Verification Program.

Receipts	Arkansas	Ashley	Chicot	Clay	Conway	Cross	Desha	Jefferson
Yield (bu)	154	173	236	154	176	158	151	165
Price received	4.11	4.54	4.63	4.63	4.58	4.48	4.41	4.70
Total crop revenue	**632.50**	**784.76**	**1092.27**	**712.75**	**806.04**	**708.27**	**666.28**	**776.08**
Operating expenses								
Seed	60.56	154.97	149.52	133.68	128.11	42.30	49.00	140.16
Fertilizers and nutrients	94.11	63.92	77.79	106.58	49.48	116.85	94.45	118.35
Chemicals	49.15	82.13	107.11	47.36	72.58	61.35	70.96	95.10
Custom applications	29.75	39.20	49.00	56.40	52.85	48.40	39.20	71.75
Diesel fuel	8.39	7.13	5.56	7.75	10.75	11.59	9.40	5.12
Repairs and maintenance	16.31	22.05	21.50	21.28	18.02	20.28	20.69	20.58
Irrigation energy costs	0.00	44.29	44.29	57.12	17.28	30.27	43.20	44.29
Labor, field activities	9.64	8.90	6.85	10.32	8.29	10.58	10.31	6.08
Other inputs and fees, pre-harvest	63.69	21.45	17.11	27.51	37.15	19.53	19.42	18.05
Post-harvest expenses	102.18	114.79	156.59	102.18	116.78	104.83	100.19	109.48
Total operating expenses	**433.79**	**558.82**	**635.31**	**570.17**	**511.28**	**465.97**	**456.82**	**628.96**
Returns to operating expenses	**198.71**	**225.95**	**456.96**	**142.58**	**294.75**	**242.30**	**209.46**	**147.12**
Capital recovery and fixed costs	70.08	94.52	86.63	92.44	81.07	100.74	91.90	84.10
Total specified expenses[a]	**506.87**	**653.33**	**721.94**	**662.61**	**592.35**	**566.71**	**548.73**	**713.06**
Returns to specified expenses	**128.63**	**131.43**	**370.33**	**50.14**	**213.69**	**141.56**	**117.56**	**63.02**
Operating expenses/yield unit	2.82	3.23	2.69	3.70	2.91	2.95	3.03	3.81
Total expenses/yield unit	3.27	3.78	3.06	4.30	3.37	3.59	3.63	4.32

continued

Table 7. Continued.

Receipts	Lawrence	Lee	Lincoln	Mississippi	Monroe	Phillips	White	Average
Yield (bu)	176	140	173	187	142	148	156	166
Price received	4.49	4.56	4.51	4.70	4.38	4.23	4.79	4.52
Total crop revenue	**789.84**	**638.46**	**779.71**	**879.55**	**621.61**	**625.80**	**747.72**	**750.78**
Operating expenses								
Seed	88.50	60.38	133.68	133.68	51.55	51.75	128.48	100.42
Fertilizers and nutrients	61.00	84.66	88.48	68.35	93.44	51.75	120.74	86.00
Chemicals	90.09	43.98	107.16	50.49	106.79	60.07	37.05	72.09
Custom applications	40.25	24.50	56.00	44.80	44.60	19.25	57.80	44.92
Diesel fuel	7.85	8.84	6.98	7.34	8.74	9.45	7.98	8.19
Repairs and maintenance	21.24	24.37	21.60	20.29	19.12	22.35	20.06	20.65
Irrigation energy costs	23.50	79.93	69.13	30.49	28.80	43.20	3.54	37.29
Labor, field activities	9.84	12.54	7.60	9.30	10.40	11.04	9.42	9.41
Other inputs and fees, pre-harvest	19.54	19.47	17.79	25.71	20.05	17.80	26.19	24.70
Post-harvest expenses	116.78	92.89	114.79	124.07	94.22	98.20	103.51	110.10
Total operating expenses	**478.59**	**451.55**	**623.20**	**514.51**	**477.70**	**384.87**	**514.77**	**513.75**
Returns to operating expenses	**311.25**	**186.92**	**156.51**	**365.05**	**143.91**	**240.93**	**232.94**	**237.02**
Capital recovery and fixed costs	90.31	110.97	92.11	88.68	85.73	102.79	84.19	90.42
Total specified expenses[a]	**568.90**	**562.52**	**715.30**	**603.18**	**563.43**	**487.65**	**598.96**	**604.17**
Returns to specified expenses	**220.94**	**75.95**	**64.41**	**276.37**	**58.17**	**138.15**	**148.75**	**146.61**
Operating expenses/yield unit	2.72	3.23	3.60	2.75	3.36	2.60	3.30	3.11
Total expenses/yield unit	3.23	4.02	4.13	3.23	3.97	3.29	3.84	3.67

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

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

County	Rice type	Seed	Fertilizers and nutrients	Herbicides	Insecticides	Fungicides and other inputs	Diesel fuel	Irrigation energy costs
Arkansas	Diamond	60.56	94.11	43.93	5.22	---	8.39	---[a]
Ashley	CLXL729	154.97	63.92	79.30	2.83	---	7.13	44.29
Chicot	CLXL745	149.52	77.79	107.11	---	---	5.56	44.29
Clay	XL753	133.68	106.58	47.36	---	---	7.75	57.12
Conway	XL753	128.11	49.48	64.90	7.68	---	10.75	17.28
Cross	Roy J	42.30	116.85	61.35	---	---	11.59	30.27
Desha	Roy J	49.00	94.45	35.84	4.75	30.38	9.40	43.20
Jefferson	XL753	140.16	118.35	93.35	---	1.75	5.12	44.29
Lawrence	CL151	88.50	61.00	86.59	---	3.50	7.85	23.50
Lee	Roy J	60.38	84.66	43.98	---	---	8.84	79.93
Lincoln	XL753	133.68	88.48	101.36	5.80	---	6.98	69.13
Mississippi	XL753	133.68	68.35	46.99	---	3.50	7.34	30.49
Monroe	Jupiter	51.55	93.44	102.41	---	4.38	8.74	28.80
Phillips	Roy J	51.75	51.75	69.93	3.62	---	9.45	43.20
White	XL753	128.48	120.74	33.44	3.62	---	7.98	3.54
Average	---	100.42	86.00	67.86	4.79	8.70	8.19	39.95

[a] Water was applied by gravity flow to RRVP fields in Arkansas County. Thus, irrigation energy costs were equal to zero for this county.

Impact of Molecular Analysis on Rice Breeding Efforts

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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 16 years. Currently there are four rice breeding programs and cooperative extension activities that utilize the laboratory. Much of the effort over the last 16 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, aromatic rice breeding, backcross populations, genomic mapping of specific traits, and seed purification. In 2016, researchers in the Molecular Genetics lab worked on projects for the rice breeding programs involving DNA marker-assisted selection for the important traits of cooking quality, aroma, rice blast disease resistance, and Clearfield herbicide resistance. Up to 24 DNA markers were used to screen 3918 samples for the Hybrid Rice Breeding Program. The projects included a large backcross population, parental materials, male-sterile and restorer lines, and selected F_1 hybrid lines in development currently. Materials screened with up to 13 markers in the Medium-Grain Rice Breeding Program included 1504 samples in the Stuttgart Initial Test and potential donors for the major rice blast disease resistance gene *Pi*-9. The Arkansas Specialty Rice Program submitted 220 samples of aromatic early generation progeny and selected entries from the Preliminary Yield Trials. The 182 samples submitted by the Long-Grain Rice Breeding Program were screened with up to 25 markers to develop a genetic fingerprint of several elite lines. Other smaller projects were conducted for the Rice Verification Program, Rice Extension Agronomy, graduate thesis programs, and proprietary industry clients. The lab processed 6138 mostly bulked genomic DNA samples in 2016, generating 56,464 data points, which represents a more than 2.6-fold increase in molecular analysis over 2015 efforts. The work was accomplished using 76 DNA template plates (96-well), 730 Polymerase Chain Reaction (PCR) plates, 159 runs on the ABI 3500xL, and 184 KASP runs.

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Introduction

DNA marker analysis can be a useful tool for rice breeders to enhance the germplasm development process. Using DNA markers enables characterization of breeding materials on a level not affected by time or environmental influences. The technology can benefit breeding programs by allowing identification of new genetic resources to increase yields and disease resistance and genotyping of parental materials for these resources prior to use in crossing. Molecular markers can be used to confirm hybridity, track alleles through generations of progeny, select those progeny containing desirable traits, confirm genotype-phenotype correlations, and determine seed purity. Molecular markers are especially useful in identifying off types and undesirable traits (such as red pericarp) long before the plants are able to flower and outcross with breeding populations in development. All of this work can enable the breeder to devote time, funds, and resources on only those materials that are selected for further development in the breeding program, and not waste efforts and money on undesirable materials that are destined to be eliminated.

Materials submitted for molecular analysis are screened with DNA markers that were determined to be informative from the parental genotyping data. The simple sequence repeat (SSR) and insertion-deletion (InDel) markers included random fingerprint markers and markers that are linked to the rice blast resistance genes *Pi-b, Pi-i, Pi-kh, Pi-ks, Pi-ta*, and *Pi-z* (Conaway-Bormans et al., 2003; Fjellstrom et al., 2004, 2006; Jia et al., 2004), aroma (Fjellstrom, pers. comm.) and amylose content (Bergman et al., 2001; McClung et al., 2004). Single nucleotide polymorphism (SNP) markers were analyzed using Kompetitive Allele-Specific Polymerase Chain Reaction (PCR; KASP™) chemistry. The KASP markers were linked to the traits of amylose (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, processed through a OneStep-96 PCR Inhibitor Removal system (Zymo Research Corporation, Irvine, Calif.), and used directly as starting template for SSR and InDel analysis. Eleven samples on the plate were assessed for DNA concentration and purity at the wavelengths 260 and 280 nm using an Eppendorf BioPhotometer spectrophotometer (Eppendorf North America, Inc., Westbury, N.Y.). Using the median DNA concentration of those 11 samples, the DNA of the entire 96-well plate was diluted in water to a 7-8 ng/µl concentration to prepare the KASP reaction template.

Polymerase Chain Reaction of SSR and InDel markers was conducted using primers pre-labeled with attached fluorophores of either HEX, FAM, or NED by adding 2 µl of starting DNA template in 25µl reactions and cycling in a Mastercycler Pro S thermal cycler (Eppendorf North America, Inc., Westbury, N.Y.) for 35 cycles of a traditional 3-step PCR protocol. To save on processing and analysis costs, PCR plates were grouped according to allele sizes and dye colors and diluted together with an epMotion 5070 liquid handling robot (Eppendorf North America, Inc., Westbury, N.Y.). Polymerase chain reaction products were resolved using capillary electrophoresis on an ABI 3500xL Genetic Analyzer. Data analysis was conducted using GeneMapper Software V5.0 (Applied Biosystems, Foster City, Calif.).

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 Pro 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.). The KASP marker for *Waxy* Exon 6 was determined to be not as reliable as the KASP marker for *Waxy* Exon 1 and the SSR marker RM190 for predicting amylose content. In the instances in which RM190 and *Waxy* Exon 1 agreed, but *Waxy* Exon 6 data contradicted the other two, the *Waxy* Exon 6 marker was ignored for allele scoring purposes.

Results and Discussion

For the hybrid rice breeding program, four male-sterile lines, seven restorer lines, 17 second generation backcross populations, and three F_1 hybrid lines were screened with markers linked to cooking quality, rice blast disease resistance, and plant height. All data is listed in Table 1.

Of the male-sterile lines, 1 has amplified alleles indicative of a low amylose phenotype, 1 has high amylose, and 2 are segregating for the trait. Two lines have *Pi-ta* resistance, and 1 line has *Pi-b* resistance in addition to *Pi-ta*. All 4 lines are semi-dwarf in stature. Of the restorer lines, 2 should have high amylose, 4 should have low amylose, and 1 should be intermediate. Two lines have *Pi-b* resistance, and 1 line is segregating for *Pi-ta* resistance. Six are semi-dwarf and 1 is tall. One of the BC_1F_2 lines should have low amylose, while the rest are segregating for the trait. One has *Pi-b* resistance, and

6 are segregating for *Pi-b*. Six are segregating for *Pi-k* resistance, while 14 have *Pi-ta* resistance and 3 are segregating for *Pi-ta*. All 17 amplified alleles indicate semi-dwarf plant height. Only 1 of the F_1 populations had all samples amplify as heterozygous with all polymorphic markers tested indicating hybridity. The first population had 83% of the samples that were male-sterile selfs, and the third population had 38% selfs of the male-sterile parent (Table 1).

Additional male-sterile and restorer lines were screened with markers linked to cooking quality, aroma, rice blast disease resistance, leaf surface, and plant height (Table 2). They were also screened with 8 random fingerprint markers (data not shown). Of 15 male-sterile lines screened in 24 sample groups, 8 have low amylose and 7 are segregating for cooking quality. Five are not aromatic, 2 are aromatic and 8 are segregating for aroma. Since the aroma trait is dominant, all 10 lines would be aromatic phenotypically. Five lines have *Pi-b* resistance and 6 are segregating for *Pi-b*. Three lines have *Pi-ta* with 4 segregating for the trait. Five lines have glabrous leaves, 5 have pubescent leaves, and 5 are segregating. All 15 lines are semi-dwarf in height. Of the 5 restorer lines, 1 has high amylose, 2 have low amylose, 1 has intermediate amylose, and 1 is segregating. Three lines are aromatic. Two are segregating for *Pi-k* resistance and 4 have *Pi-ta* resistance. All 5 lines have glabrous leaves and are semi-dwarf in stature (Table 2).

Lines for the Stuttgart Initial Test (SIT), Clearfield SIT (CSIT), an F_7 generation population, and the first generation of two backcross populations were screened for the Medium-Grain Rice Breeding Program (Table 3). In the CSIT samples, 82% have intermediate amylose, 100% have a marker prediction of a weak Rapid Visco Analyzer result (RVA), 83% have a medium to high gelatinization temperature, and 99.6% are non-aromatic. Only 33% have *Pi-k* resistance, 19% have *Pi-ta* resistance, 10% have *Pi-z* resistance, and 2% have *Pi-b* resistance. Over 97% of the samples are from semi-dwarf plants, and over 97% are Clearfield herbicide resistant at the S653D locus. In the SIT samples, 60% have intermediate amylose, 100% have a weak RVA, 60% have a medium to high gelatinization temperature, and 99% are non-aromatic. Only 20% have *Pi-k* resistance, 16% have *Pi-ta* resistance, and 14% have *Pi-z* resistance. Over 96% of the samples are from semi-dwarf plants (Table 3).

The F_7 population has low amylose and gelatinization temperature, while the BC_1F_1 populations both have intermediate amylose, a medium to high gelatinization temperature, and are segregating for rice blast disease resistance at the *Pi-ta* locus (Table 3).

Early generation progeny in development in the aromatic rice breeding program were screened with markers linked to cooking quality, aroma, and rice blast disease resistance (Table 4). Of the 11 lines, 1 has low amylose, 4 are segregating, and 5 have a mixture of genotypes, with 4 lines being mostly low and 1 line mostly intermediate. All 11 have a weak RVA. On gelatinization temperature, the marker results corresponded with those on amylose content. One line has a low gelatinization temperature, 1 has a medium to high temperature, 4 are segregating, and 5 have a mixture of genotypes, with 4 lines being mostly low and 1 line mostly medium to high. Five lines are aromatic, 2 lines are segregating (phenotypically aromatic), 1 line is not aromatic, and 3 lines are a mixture of genotypes with most of the samples being aromatic. One line has

Pi-b resistance and 1 line is segregating for *Pi-b*. Nine lines are segregating for *Pi-k* resistance. One line is segregating for *Pi-ta*, while 3 lines are a mixture of genotypes ranging from 11% to 21% resistant at the *Pi-ta* locus (Table 4).

Significance of Findings

Marker screening of hybrid breeding materials revealed that progress is being made in reducing trait segregation and identifying promising lines to advance. It allowed characterization of male-sterile and restorer lines, enabling the breeder to eliminate those lines that either had alleles linked to undesirable phenotypes, or were segregating to such an extent that they were not usable without a tremendous prior investment of resources and effort. Marker analysis in hybrid breeding, medium-grain breeding, and aromatic breeding enabled the breeders to track progress of lines in development, assess the status of the populations, and eliminate those materials that are not desirable for inclusion in future rice breeding efforts. This saves time, resources, and funds that would otherwise be utilized on breeding materials destined for elimination from the development pipelines. Establishing a molecular database on selected elite lines for the long-grain rice breeding program allows for a comparison of marker data for future studies.

Acknowledgments

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Table 1. Hybrid Rice Breeding Program populations screened with markers linked to cooking quality, rice blast disease resistance, and plant height.

Test population	Amylose RM190	*Pi-b* RM208	*Pi-k* RM224	*Pi-ta* *Pi-indica*	*Pi-z* AP5659	*sd1* RM1339
MaleSter_2	Seg[a]	1%	3%	94%	0%	SmDwf
MaleSter_8	Low	89%	0%	92%	0%	SmDwf
3xx_A/B	High	0%	0%	0%	0%	SmDwf
8xx_A/B	Seg	0%	0%	0%	0%	SmDwf
Restorer_35	High	0%	0%	0%	0%	SmDwf
Restorer_36	Low	0%	0%	86%	0%	SmDwf
Restorer_37	Low	100%	0%	0%	0%	SmDwf
Restorer_39	High	0%	0%	Seg	0%	SmDwf
Restore_39x	Int	0%	0%	0%	0%	Tall
Restorer_40	Low	100%	0%	0%	0%	SmDwf
Restorer_45	Low	0%	0%	0%	0%	SmDwf
BC1F2_41	Seg	0%	0%	100%	0%	SmDwf
BC1F2_54	Seg	0%	Seg	100%	0%	SmDwf
BC1F2_64	Seg	0%	Seg	Seg	0%	SmDwf
BC1F2_81	Seg	0%	Seg	100%	0%	SmDwf
BC1F2_95	Seg	0%	0%	100%	0%	SmDwf
BC1F2_101	Seg	0%	0%	100%	0%	SmDwf
BC1F2_112	Seg	0%	Seg	100%	0%	SmDwf
BC1F2_123	Seg	0%	0%	100%	0%	SmDwf
BC1F2_125	Seg	0%	Seg	100%	0%	SmDwf
BC1F2_174	Low	0%	0%	100%	0%	SmDwf
BC1F2_271	Seg	Seg	0%	Seg	0%	SmDwf

continued

Table 1. Continued.

Test population	Amylose RM190	*Pi-b* RM208	*Pi-k* RM224	*Pi-ta* *Pi-indica*	*Pi-z* AP5659	*sd1* RM1339
BC1F2_273	Seg	Seg	0%	Seg	0%	Seg
BC1F2_371	Seg	Seg	0%	100%	0%	SmDwf
BC1F2_713	Seg	Seg	0%	100%	0%	SmDwf
BC1F2_741	Seg	Seg	0%	100%	0%	SmDwf
BC1F2_761	Seg	100%	0%	100%	0%	SmDwf
BC1F2_782	Seg	Seg	Seg	100%	0%	SmDwf
F1_34xB_1	83% Self	0%	83% Self	83% Self	0%	83% Self
F1_34xB_2	Seg	0%	Seg	Seg	0%	Seg
F1_34xB_3	38% Self	0%	38% Self	38% Self	0%	SmDwf

[a] Seg = segregating, Int = intermediate, and SmDwf = semi-dwarf.

Table 2. Hybrid Rice Breeding Program populations screened with markers linked to cooking quality, aroma, rice blast disease resistance, leaf surface, and plant height.

Test population	Amylose RM190	2AP Aroma	*Pi-b* RM208	*Pi-k* RM224	*Pi-ta* *Pi-ind*	*Pi-z* 5659	Glabrous GlabSNP	*sd1* RM1339
MS_3x_1	Low	N-Aro[a]	S	S	R	S	Glab	SmDwf
MS_71	Low	Seg	S	S	Seg	S	Pub	SmDwf
MS_73	Seg	Seg	Seg	S	S	S	Pub	SmDwf
MS_77	Seg	Seg	Seg	S	S	S	Seg	SmDwf
MS_78	Low	N-Aro	R	S	R	S	Glab	SmDwf
MS_79	Low	Seg	Seg	S	Seg	S	Seg	SmDwf
MS_81	Seg	Seg	R	S	S	S	Pub	SmDwf
MS_82	Low	Seg	R	S	S	S	Seg	SmDwf
MS_83	Low	Aro	Seg	S	S	S	Pub	SmDwf
MS_85	Seg	N-Aro	S	S	R	S	Glab	SmDwf
MS_86	Seg	Seg	Seg	S	Seg	S	Seg	SmDwf
MS_89	Seg	N-Aro	S	S	Seg	S	Glab	SmDwf
MS_81-0	Low	Aro	R	S	S	S	Pub	SmDwf
MS_81-6	Seg	Seg	Seg	S	S	S	Seg	SmDwf
MS_91	Low	N-Aro	R	S	S	S	Glab	SmDwf
Res_19	Low	N-Aro	S	S	R	S	Glab	SmDwf
Res_35	Int	Aro	S	Seg	R	S	Glab	SmDwf
Res_37	Low	N-Aro	S	S	R	S	Glab	SmDwf
Res_59	Seg	Aro	S	Seg	R	S	Glab	SmDwf
Res_60	High	Aro	S	S	S	S	Glab	SmDwf
MS_71x	Low	Aro	S	S	S	S	–	SmDwf
MS_73x	Low	Aro	S	S	S	S	–	SmDwf
MS_77x	Low	Seg	Seg	S	S	S	–	SmDwf
MS_79x	Low	Seg	Seg	S	Seg	S	–	SmDwf
MS_81x	Seg	Seg	Seg	S	Seg	S	–	SmDwf
MS_82x	Seg	Seg	Seg	S	Seg	S	–	SmDwf
MS_83x	Low	Seg	R	S	S	S	–	SmDwf
MS_86x	Seg	Seg	Seg	S	Seg	S	–	SmDwf
MS_81-6x	Low	N-Aro	R	S	S	S	–	SmDwf

[a] Seg = segregating. Int = intermediate, Aro = aromatic, N-Aro = non-aromatic, Glab = glabrous, Pub = pubescent, SmDwf = semi-dwarf, S = susceptible, and R = resistant.

Table 3. Medium-Grain Rice Breeding Program populations screened with markers linked to cooking quality, aroma, rice blast disease resistance, and plant height. The Clearfield Stuttgart Initial Test populations were also screened for Clearfield herbicide resistance.

Test Samples	Amylose RM190	Amylose Exon 1	Amylose Exon 6	RVA Exon 10	Gel Temp Alk	2AP Aroma	*Pi-b* RM208	*Pi-k* RM224	*Pi-ta* *Pi-ind*	*Pi-z* 659-1	*Pi-z* 659-5	*sd1* 1339	CL S653D
CSIT	82% Int 16% Lo	83% Int 16% Lo	4% Hi % Int 16% Lo	100% Weak	15% Lo 83% M-H	99.6% N-Aro	2% R 1% Seg 97% S	33% R 63% Seg 4% Seg	19% R 8% Seg 73% S	10% R 2% Seg 88% S	10% R 2% Seg 88% S	97% SmDwf	97% R
SIT	0.4% Hi 58% Int 40% Lo	60% Int 40% Lo	13% Hi 39% Int 39% Lo	100% Weak	39% Lo 60% M-H	99% N-Aro	100% S	20% R 76% Seg 4% S	16% R 9% Seg 75% S	13% R 6% Seg 81% S	14% R 4% Seg 81% S	96% SmDwf	--
1111	100% Lo	100% Lo	100% Lo	--	100% Lo	--	--	--	100% S	--	--	--	
418	100% Int.	100% Int. High	Seg	--	100% M-H	--	--	--	Seg	--	--	--	--
420	100% Int	100% - Int High	100% Int	--	100% M-H	--	--	--	Seg	--	--	--	--

[a] Seg = segregating. Int.= intermediate, Hi = high, Lo = low, Int-H = intermediate to high, M-H = medium-high, N-Aro = non-aromatic, SmDwf = semi-dwarf, S = susceptible, and R = resistant.

Table 4. Aromatic Rice Breeding Program populations screened with markers linked to cooking quality, aroma, and rice blast disease resistance.

Test Samples	Amylose RM190	Amylose Exon 1	Amylose Exon 6	RVA Exon 10	Gel Temp Alk	2AP Aroma	*Pi-b* RM208	*Pi-k* RM224	*Pi-ta* *Pi-ind*	*Pi-z* AP659-1	*Pi-z* AP659-5
PanA01	Seg	Seg	Seg	100% Weak	Seg	Seg	Seg	Seg	Seg	100% S	100% S
PanA02	21% Int 61% Lo 18% Seg	21% Int 61% Lo 18% Seg	21% Int 61% Lo 18% Seg	100% Weak	15% M-H 70% Lo 12% Seg	100% Aro	100% S	27% Seg 73% S	21% R 79% S	100% S	100% S
PanA03	Seg	Seg	Seg	100% Weak	Seg	Seg	100% S	Seg	100% S	100% S	100% S
PanA04	Seg	Seg	Seg	100% Weak	Seg	100% Aro	100% S	Seg	100% S	100% S	100% S
PanA05	78% Int 11% Lo 11% Seg	78% Int 11% Lo 11% Seg	78% Int 11% Lo 11% Seg	100% Weak	67% M-H 22% Lo 11% Seg	100% Aro	100% S	Seg	100% S	100% S	100% S
PanA06	Seg	Seg	Seg	100% Weak	Seg	100% Aro	100% S	Seg	100% S	100% S	100% S
PanA07	Lo	Lo	Lo	Weak	M-H	Aro	S	S	S	S	S
PanA08	12% Int 82% Lo 6% Seg	12% Int 82% Lo 6% Seg	12% Int 82% Lo 6% Seg	100% Weak	24% M-H 76% Lo	82% Aro 6% N-Aro 12% Seg	100% S	Seg	100% S	100% S	100% S
PanA09	35% Int 59% Lo 6% Seg	35% Int 59% Lo	35% Int 59% Lo	100% Weak	24% M-H 65% Lo	82% Aro 18% N-Aro	100% S	100% S	12% R 88% S	100% S	100% S
PanA10	32% Int 63% Lo 5% Seg	42% Int 54% Lo	42% Int 54% Lo	100% Weak	19% M-H 77% Lo 4% Seg	73% Aro 27% N-Aro	100% S	27% Seg 69% S	11% R 89% S	100% S	100% S
PanA11	–	Lo	Lo	Weak	Low	100% N-Aro	100% R	100% S	–	100% S	100% S

[a] Seg = segregating. Int = intermediate, M-H = medium-high, Aro = aromatic, N-Aro = non-aromatic, S = susceptible, and R = resistant

2016 Screening Uniform Rice Regional Nursery Lines for Resistance to Rice Blast Disease

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Abstract

In 2016, 199 entries in the Uniform Regional Rice Nursery (URRN) collection were screened with a range of reference isolates of the rice blast pathogen. The URRN collection, and two susceptible control varieties M204 and Francis, were evaluated for overall disease resistance to 12 reference isolates representing 10 races. The greenhouse isolate IB33 (race IB-33) was the most virulent isolate, with only 13 lines having resistance to this isolate. Approximately 40% (81 lines) were resistant to islolate TM2 (race k), 50% of the lines (101 and 102 lines) were resistant to two IB-49 isolates (A119 and 49D, respectively), and about 80% of the lines were resistant to the four isolates IB54, 24, A264, and ID13. Two lines, RU1403138 and RU1602082, were resistant to all isolates. Thirty-five lines were resistant to 11 isolates, including 2 lines, RU1303138 and RU1603089 that were only susceptible to 49D; RU1603113 was only susceptible to TM2, and another 32 lines were only susceptible to the IB33 isolate. Four lines (RU1401145, RU1601067, RU1504157, and RU1504114) were susceptible to all 12 isolates. Seven lines were susceptible to 11 isolates, and 5 lines were susceptible to 10 isolates. Overall, the 2016 URRN lines had broader resistance than those evaluated in previous years. All of the URRN screening data can be used by the breeders in the selection process.

Introduction

Rice is an important crop in the United States, which is grown on approximately 1.5 M acres, producing 10 billion pounds of rice, with the value of $2 billion annually. Rice production in the U.S. is less than 2% of the world production, but accounts for 10% of exports making the U.S. the 5th largest rice exporter. The ubiquitous disease rice blast, caused by the fungus *Magnaporthe oryzae* (anamorph: *Pyricularia oryzae*), threatens rice production in the U.S. and worldwide. Although this disease can be controlled by some fungicides, it is not the preferred management option due to environmental concerns and the costs. Growing resistant cultivars is the most economic and effective way to

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manage this disease. Multiple races exist in the *Magnaporthe oryzae* population in the U.S. For example, race IB49 and IC-17 remain the most prevalent races in Arkansas (Correll et al., 2000; Xia et al., 2000), with occasional epidemics due to the "race K" type isolates (Lee et al., 2005). It is necessary to know the resistance spectrum of new cultivars to the prevelant rice blast races in the southern growing region before they are released. This study involved testing the Uniform Regional Rice Nursery (URRN) lines with 12 U.S. reference isolates of *Magnaporthe oryzae*, which are representative of the pathogen population in Arkansas.

Procedures

The 199 rice breeding lines developed by the rice breeders from Arkansas, Louisiana, Mississippi, and Texas were tested with 12 rice blast reference isolates (Table 1). The rice cultivars M204 and Francis were included in each test as the susceptible control. Rice seed was 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 entries and 2 cells of the susceptible controls M204 and 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 RBA plates for 7 to 10 days. Spores were collected in cool water and adjusted to a concentration of 200,000 spores/mLper isolate. Each tray was inoculated with 50 mLof 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, 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 7th 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

In 2016, the seed of 199 URRN lines (Entry 108 Variety RU1501108 without seed) were evaluated. The lines were tested with 12 U.S. reference isolates of *Magnaporthe oryzae*. The isolate IB33, originally recovered from rice under greenhouse conditions by F.N. Lee, was the most virulent isolate, with only 13 lines resistant to this isolate. Isolates TM2 (race k), A119, and 49D (both race IB49) were relatively more virulent, with only 81, 101 and 102 lines (about 40%, to 50%, respectively, of total) resistant to these three isolates. Over 70% (73% to 88%) of the lines were resistant to six isolates A598 (race IB49), ZN15 (race IB-1), IB54 (race IB54), #24 (race IG1), A264 (race IC17) and ID13 (race ID13). Isolates A119, 49D, and A598 were classified as race IB49. However, about 50% of the lines were resistant to isolate A119 and 49D, and more than

70% of the lines were resistant to A598. Again, the difference in virulence of the three IB49 (A119, A598, and 49D) isolates suggested there is a difference in their virulence characteristics. The number of lines that were resistant or susceptible to each isolate is shown in Fig. 1.

Two lines (RU1403138, and RU1602082) were resistant to all tested isolates and 35 lines (RU1303138, RU1603089, RU1603113, RU1003123, RU1502115,RU1602071, RU1601099, RU1602195, CL111, RU1403089, RU1203190, RU1602103, RU1601111, RU1602112, RU1602134, RU1602146, RU1503169, RU1601170, RU1503175, RU1602177,RU1601185, CL153, RU1003098, RU1602062, RU1602065, RU1601070, RU1601121, RU1601127, RU1602128, RU1601130, RU1602131, RU1503132, RU1303163, RU1601173, and RU1602140) were resistant to 11 isolates. Lines RU1303138 and RU1603089 were only susceptible to isolate 49D (race IB49); RU1603113 was only susceptible to TM2 (race k); Another 32 lines were only susceptible to the isolate IB33. A total of 40 lines were resistant to 10 isolates, and 27 lines were resistant to 9 isolates, so more than 50% of the tested lines showed some resistance, which is a higher percentage than the materials evaluated in 2014 and 2015. Four lines (RU1401145, RU1601067, RU1504157, and RU1504114) were susceptible to all isolates; seven lines (RU1502094, RU1404156, RU1401105, RU1601084, RU1604197, RU1601004, and RU1601081) were only resistant to one isolate. Five lines (RU1104077, RU1404122, DMND, M206, and RU1504196) were only resistant to two isolates. The 37 most resistant and 11 most susceptible lines were listed in Table 2. The number of lines that were resistant to a certain number of isolates was shown in Fig. 2. A complete examination of the entry by isolate interactions is available on line at http://www.uark.edu/ua/jcorrell/data/2016URRN.xls.

Significance of Findings

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

Acknowledgments

The authors would like to thank the rice producers of Arkansas for their financial support of the research through monies administered by the Arkansas Rice Research and Promotion Board and for the continued support of the University of Arkansas System Division of Agriculture.

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Table 1. Background information on the 12 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	1959	LA
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
ID13				ID13	1982	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 (37) and susceptible (11) lines tested.

Entry	Variety	A119 IB-49	A264 IC-17	A598 IB-49	ZN7 IE-1	ZN15 IB-1	ZN46 IC-1	IB33 IB33	1B54 1B54	ID13 ID13	24 IG-1	TM2 Race K
43	RU1403138	0	0	2	1	0	0	3	0	0	0	0
82	RU1602082	0	0	0	0	0	0	3	0	0	0	0
32	RU1303138	0	0	0	0	0	0	3	0	0	0	0
89	RU1603089	0	0	0	0	0	0	3	0	0	0	0
113	RU1603113	2	0	3	3	0	0	3	0	0	0	5
6	RU1003123	0	1	0	1	0	0	4	0	0	0	1
34	RU1502115	0	0	0	0	0	0	4	0	0	0	1
71	RU1602071	0	0	0	0	0	1	4	0	0	0	0
99	RU1601099	0	0	0	0	0	0	4	0	0	0	1
195	RU1602195	0	0	0	0	0	0	4	0	0	0	1
17	CL 111	0	0	0	0	0	0	5	0	0	0	1
52	RU1403089	0	1	0	0	0	0	5	0	0	0	1
78	RU1203190	1	0	0	1	0	0	5	0	0	0	1
103	RU1602103	0	0	1	0	0	3	5	0	0	1	1
111	RU1601111	0	0	0	0	0	0	5	0	0	0	1
112	RU1602112	0	0	0	0	0	0	5	0	0	0	1
134	RU1602134	0	0	0	0	0	0	5	0	0	0	1
146	RU1602146	0	0	0	0	0	0	5	0	0	0	1
169	RU1503169	0	0	0	0	0	0	5	0	0	0	1
170	RU1601170	0	0	1	0	0	0	5	0	0	0	1
175	RU1503175	0	0	1	3	0	0	5	0	0	0	1
177	RU1602177	1	0	0	0	0	0	5	0	0	1	1
185	RU1601185	0	0	0	3	0	0	5	0	0	0	1
18	CL 153	0	0	0	0	0	0	6	0	0	0	1
26	RU1003098	0	2	0	0	0	0	6	0	0	0	1
62	RU1602062	1	1	0	0	0	3	6	0	0	0	1
65	RU1602065	1	0	0	3	0	0	6	0	0	0	1
70	RU1601070	0	0	0	0	0	0	6	0	0	0	1
121	RU1601121	0	0	0	0	0	0	6	0	0	0	0
127	RU1601127	0	0	0	0	0	0	6	0	0	0	1
128	RU1602128	0	0	1	0	0	0	6	0	0	0	1

continued

Table 2. Continued.

Entry	Variety	A119 IB-49	A264 IC-17	A598 IB-49	ZN7 IE-1	ZN15 IB-1	ZN46 IC-1	IB33 IB33	1B54 1B54	ID13 ID13	24 IG-1	TM2 Race K
43	RU1403138	0	0	2	1	0	0	3	0	0	0	0
130	RU1601130	0	1	0	0	0	0	6	0	0	3	1
131	RU1602131	1	0	0	0	0	0	6	0	0	0	0
132	RU1503132	0	0	0	0	0	0	6	0	0	0	0
163	RU1303163	3	1	0	0	0	0	6	0	0	0	1
173	RU1601173	0	0	0	0	0	0	6	0	0	0	1
140	RU1602140	0	0	0	0	0	0	7	0	0	0	0
31	RU1502094	6	0	4	4	4	5	5	6	6	6	6
33	RU1404156	6	3	4	4	4	5	6	6	4	6	8
64	RU1401105	6	3	5	5	4	4	6	5	5	6	7
84	RU1601084	6	4	4	5	4	5	6	5	1	5	6
197	RU1604197	6	5	3	5	4	5	6	6	4	6	6
4	RU1601004	6	6	6	6	3	6	7	6	4	6	7
81	RU1601081	6	4	5	6	4	6	7	5	0	4	6
47	RU1401145	6	4	4	6	4	5	6	6	5	5	6
67	RU1601067	6	5	5	6	5	5	6	6	4	6	6
74	RU1504157	7	4	5	5	4	4	6	6	4	6	7
53	RU1504114	6	4	6	5	5	4	7	5	6	5	7
31	RU1502094	6	0	4	4	4	5	5	6	6	6	6

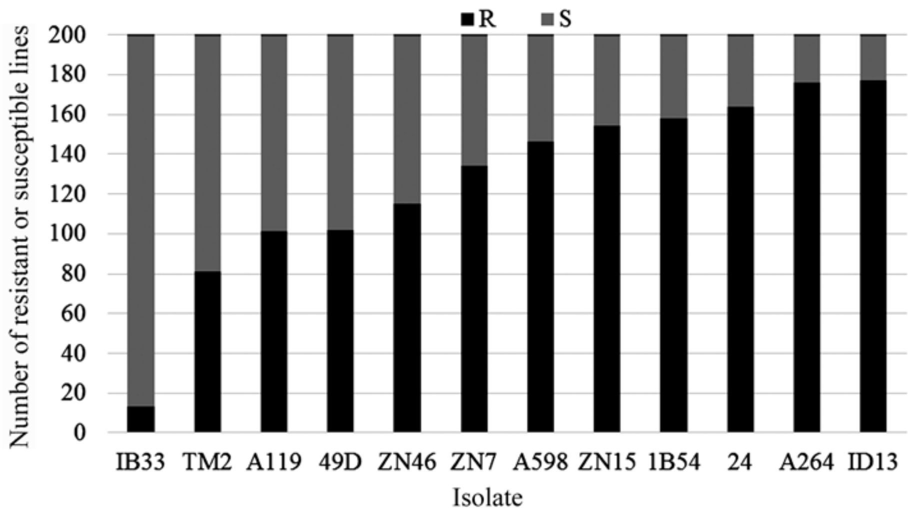

Fig. 1. Proportion of the number of rice lines that were resistant (rating scale 0 to 3, as 0 is most resistant) and susceptible (rating scales 4 to 9, as 9 is the most susceptible) to a given reference isolate.

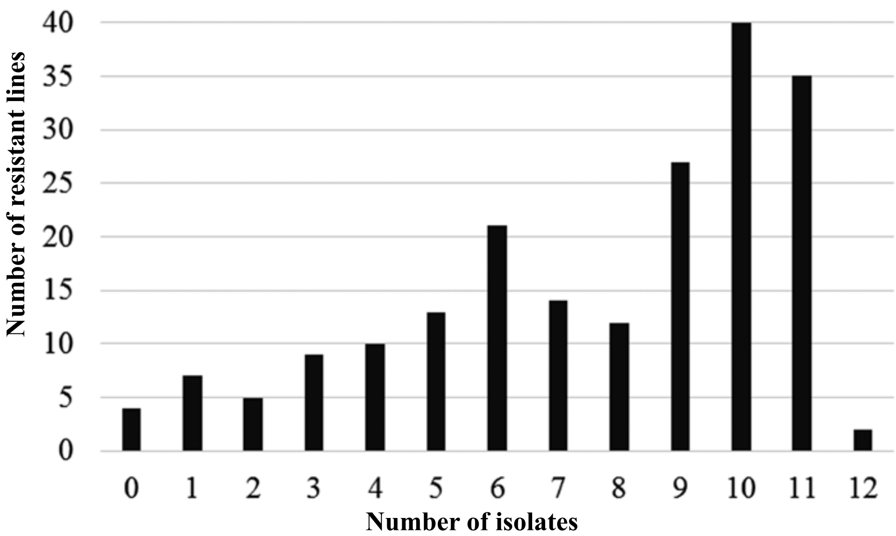

Fig. 2. Distribution of the number of rice lines that were resistant to 0 isolates, 1 isolate, 2 isolates, etc. For example, 4 rice lines were not resistant to any isolates and 2 lines were resistant to all 12 reference isolates.

Screening of Diverse Rice Cultivars for Heat Tolerance and Grain Quality Under High Nighttime Temperature

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Abstract

In this study, we screened a set of diverse rice cultivars for their response to high nighttime temperature (HNT) with the objective of identifying lines for heat tolerance and grain quality under HNT. The genotypes were screened for HNT during the flowering stage in a) growth chamber, b) under controlled environment conditions in the greenhouse, and c) in the field at 2 locations, the University of Arkansas System Division of Agriculture's Rice Research and Extension Center, Stuttgart, Ark., and the University of Arkansas System Division of Agriculture's Agricultural Research and Extension Center farm in Fayetteville, Ark. The genotypes include the heat tolerant *indica* cultivar Nagina22 (N22), the US tropical *japonica* cultivars Bengal and Kaybonnet, and sensitive *indica* cultivars Zhe733 and Ao Chiu 2 Hao. The cultivars Bengal and Kaybonnet displayed heat tolerance and grain quality equivalent to that of N22. The long-grain Kaybonnet exhibited the lowest level of chalky grain under HNT, and thus is of value for genetic studies in grain quality.

Introduction

Increased temperature has been recognized as a factor reducing yield and quality in rice, with varying effects on the three growth stages: a) vegetative–establishment to panicle initiation; b) reproductive–panicle initiation to flowering; and c) ripening–flowering to grain maturation (Welch et al., 2010). Rice grain yield can be affected by high temperatures through two mechanisms: i) high maximum temperatures with high humidity can cause spikelet sterility and reduce grain quality, and (ii) increased nighttime temperatures that reduce assimilate accumulation (Wassmann et al., 2009).

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Studies on the impacts of temperature on rice grain yield in Asia show that grain yield declined by 10% for each 1 °C increase in minimum (nighttime) temperature and that the annual mean maximum and minimum temperatures increased by 0.35 °C (32.63 °F) and 1.13 °C (34.03 °F), respectively (Peng et al., 2004). In temperate regions, high nighttime temperature (HNT) during grain filling has been shown to cause chalkiness in rice (Counce et al., 2005; Lanning et al., 2011), that causes reduction in head rice yield, grain quality and market value.

The reproductive stage in rice is more heat sensitive than the vegetative stage (Yoshida et al., 1981), affecting anthesis and micro-gametogenesis, leading to reduction in panicle dry weight. High temperature during the ripening phase in rice primarily affects grain yield and quality by increases in white chalky rice and reductions in grain weight, grain size, grain filling as well as amylose content (Yoshida et al., 1981). These effects can be caused by excessive energy consumption to meet the respiratory demand of developing seed under high temperature, or higher grain dry matter accumulation rate with a shortened grain-filling period.

In recent years, high nighttime temperature during grain filling of rice has been seen to be one of the major causes of reduction in head rice yield (HRY) and grain chalkiness in both field and controlled climate experiments, threatening the stability of the rice industry (Counce et al., 2005). Rice grain quality is dependent on HRY and the chalk percentage, or chalkiness, causing a major reduction of rice grain quality.

Genetic variation for grain yield and quality under HNT has been found together in genotypes such as N22 (González-Schain et al., 2016), as well as in transgenic rice lines overexpressing the HYR gene (Ambavaram et al., 2014), suggesting that the two traits may be physiologically related in some genotypes. We screened a set of 5 cultivars, of which 2 were adapted to the U.S., for grain yield and quality under HNT in controlled and field environments, as a step towards genetic analysis of heat tolerance and HNT quality traits. This will aid in the development of improved cultivars.

Procedures

Plant Growth Conditions and Temperature Treatment

A set of rice genotypes including tropical *japonica* US varieties (Kaybonnet, Bengal), and *indica/aus* genotypes (Zhe733, Ao Chiu 2 Hao, and a well-known heat tolerant cultivar Nagina 22/N22), were screened under temperature stress treatments for evaluating grain yield and quality parameters. To evaluate heat tolerance, we measured the number (%) of filled grains per panicle from the different experimental treatments compared to control. Screening for heat tolerance and grain quality under HNT was conducted in various environmental conditions. In controlled growth chamber conditions, plants at the R2 booting stage onwards were treated to HNT of 28 °C (82.4 °F) while controls were maintained at 22 °C (71.6 °F) with constant day temperature of 30 °C (86 °F).

Screening within a field environment was conducted at two locations during the summer 2016 season. Plants were sown in the field at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center in Stuttgart, Ark., under well-watered conditions. Temperature was recorded throughout the growth period, showing HNT during most of the flowering and grain maturity period (Fig. 1). The same genotypes were also grown in the field at the University of Arkansas System Division of Agriculture's Agricultural Research and Extension Center farm in Fayetteville, Ark., which showed lower night temperatures. Additional control plants were also grown under controlled greenhouse conditions during the summer of 2016, temperatures were recorded and data from this screen was used as the normal temperature treatment. At physiological maturity in all screens, seeds were harvested, air-dried and used for grain phenotyping and chalk measurements.

Chalk Measurement

Rough rice was de-hulled using a manually-operated de-huller (Rice Husker TR120). Chalkiness was measured using an image analysis system WinSEEDLE™ Pro 2005a (Regent Instruments Inc., Sainte-Foy, Quebec, Canada) and expressed as percent of affected grains in the projected area. Data shown are the average of 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.

Results and Discussion

The tropical *japonica* U.S. varieties Kaybonnet and Bengal, and *indica/aus* genotypes Zhe733, Ao Chiu 2 Hao, and N22, were evaluated for grain yield and quality parameters under heat stress and control conditions. The percent filled grain calculated for the treatments are shown in Fig. 2A and include: a) field condition (FC) harvest from Stuttgart, that showed heat-stress (Fig. 1) on sensitive cultivars; b) controlled greenhouse (GH) conditions maintained at constant 22 °C (71.6 °F) night and 30 °C (86 °F) day temperature throughout life cycle, and c) heat stress (HS) HNT treatments in growth chambers from R2 booting stage to seed harvest [28 °C (82.4 °F) night and 30 °C (86 °F) day]. The heat stress treatment in the growth chamber distinguishes the two sensitive genotypes, Ao Chiu 2 Hao and Zhe733, from the tolerant cultivars (N22, Bengal, and Kaybonnet) which show >85% filled grain/panicle (seed set) under controlled HNT treatment given from anthesis to maturity and >90% seed set in the field HNT treatment.

The air-dried, de-hulled seed were measured for chalkiness using an image analysis system WinSEEDLE™ Pro 2005a and expressed as a) percent number of grain showing >50%, and b) the percent showing >25% chalkiness (Fig. 2B). Kaybonnet shows the lowest level of chalky grain with < 2% and 4% grain showing >50% and >25% chalky grain, respectively, under the stringent screen in the growth chamber. Kaybonnet also displays no significant level of chalkiness in the field and greenhouse control. On the other hand, the other heat-tolerant genotypes Bengal and N22 show a higher level of chalkiness, probably more evident in the shorter grain structure. The heat-sensitive cultivars Zhe733 and Ao Chiu 2 Hao display a high level of chalkiness in all conditions, suggesting an unstable grain quality even under normal conditions.

To characterize other grain quality parameters, image analysis by WinSEEDLE™ Pro 2005a enabled measurement of grain length, grain width, grain thickness and grain length/width ratio. The data indicate that these grain quality features are not significantly affected by the heat stress (Fig. 2), even in the most severe growth chamber treatment all through the reproductive phase. The data also shows that Kaybonnet is a long slender grain variety compared to the smaller grain heat-tolerant N22 and Bengal.

Significance of Findings

In this report, we show results on the comparison of different screening methods to identify varieties that are heat tolerant, as shown by their low reduction in seed set under continuous HNT stress during the fertilization, ripening and maturation phases. Subsequently, the same screen reveals the varieties that maintain high grain quality represented by low chalky grain and long-grain length. These cultivars can now be studied to determine the genes involved in heat tolerance and grain quality under HNT.

Acknowledgments

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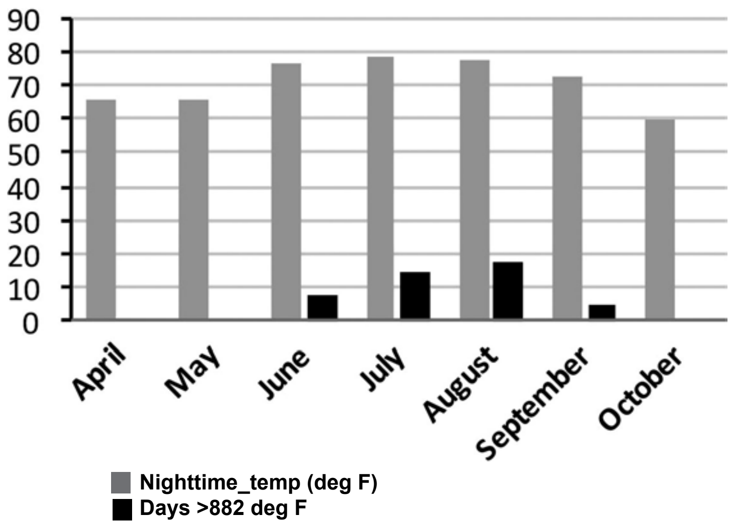

Fig. 1. Nighttime temperature at field screen in Stuttgart. Temperature of field at Stuttgart was recorded for the year 2016 rice growing season. The average nighttime temperature shows a range between 65 °F and 78 °F, and the number of days with nighttime temperature above 82 °F or 28 °C, considered as high nighttime temperature, are shown.

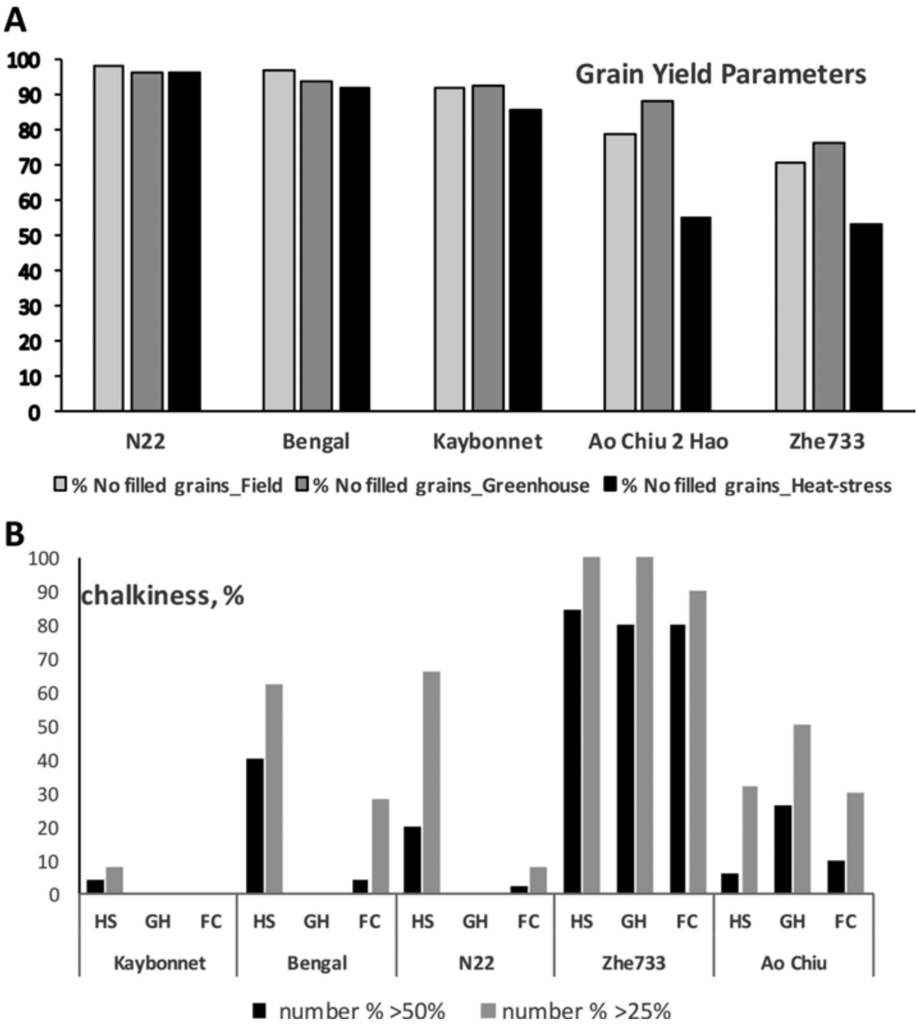

Fig. 2. Effect of high nighttime temperature (HNT) on grain yield parameters and chalkiness percent of brown grain of diverse rice cultivars. Plants at R2 stage were treated to HNT of 28 °C until maturity with controls maintained at 22 °C. The daytime temperature was kept constant at 30 °C. At physiological maturity, seeds were harvested, air-dried, and de-hulled using a manually operated de-huller (Rice Husker TR120). (A) grain yield parameter percent number filled grains was measured for the grain harvested from field (Stuttgart), greenhouse (Fayetteville), and heat stressed treatment in growth chamber. (B) chalkiness was measured using an image analysis system (WinSEEDLE™ Pro 2005a) and expressed as percent of grain projected area. Chalkiness is reported for the percentage of grain showing >25% and >50% chalkiness. Treatments are: HS – heat stress, GH – greenhouse control conditions, FC – field conditions grown in Stuttgart. Data are the means of two biological replicates with each replicate measured twice using 100 grain.

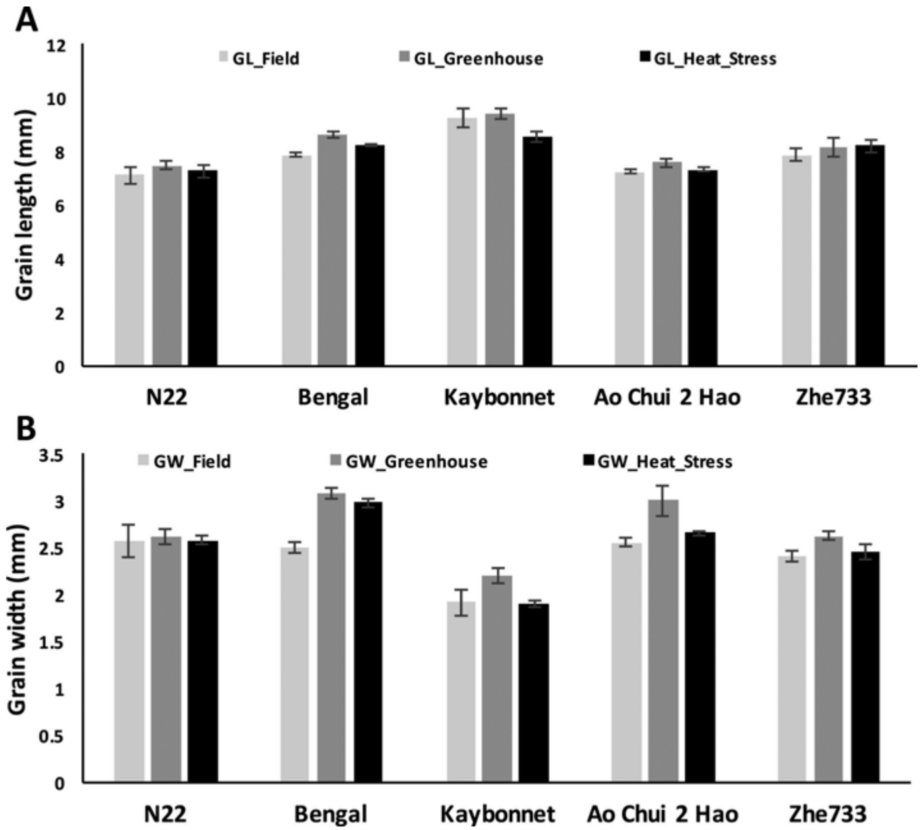

Fig. 3. Effect of high nighttime temperature (HNT) on grain length nd width of brown grain of diverse rice cultivars. Plants at R2 stage were treated to HNT of 28 ºC until maturity with controls maintained at 22 °C. The daytime temperature was kept constant at 30 ºC. At physiological maturity, seeds were harvested, air-dried, and de-hulled using a manually operated de-huller (Rice Husker TR120). (A) Grain length and (B) 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.

Breeding and Evaluation for Improved Rice Varieties—The Arkansas Rice Breeding and Development Program

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Abstract

The Arkansas rice breeding program has the ongoing goal to develop new long- and medium-grain cultivars as well as specialty cultivars including aromatics and Japanese quality short grains. Cultivars are evaluated and selected for desirable characteristics. Those with desirable qualities which require further improvement are utilized as parents in future crosses. Important components of this program include: high-yield potential, excellent milling yields, pest and disease resistance, improved plant type (i.e. short stature, semidwarf, shorter maturity, erect leaves), and superior grain quality (i.e. low chalk, cooking, processing and eating). New cultivars are continually being released to rice producers for the traditional southern U.S. markets as well as for the emerging specialty markets, which are gaining in popularity with rice consumers. This report describes the progress of the long-grain and specialty rice pure-line rice breeding effort at the University of Arkansas System Division of Agriculture.

Introduction

The rice breeding and genetics program at the University of Arkansas System Division of Agriculture's, Rice Research and Extension Center (RREC), Stuttgart, Ark., is by nature a continuing project with the goal of producing improved rice cultivars for rice producers in Arkansas and the southern U.S. rice-growing region. The Arkansas rice breeding program is a dynamic team effort involving breeders, geneticists, molecular

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geneticists, pathologists, soil scientists, physiologists, entomologists, economists, systems agronomists, weed scientists, cereal chemists, extension specialists, and statisticians. We also encourage input from producers, millers, merchants, and consumers. As breeders, we integrate information from all of these disciplines to make selections that are relevant to the needs of the entire rice industry. We are always looking for ways to enable the producer to become more economically viable, adding value to their product. Breeding objectives shift over time to accommodate the demands of these players.

Breeding objectives for improved long-grain and specialty rice cultivars include: standard cooking quality, excellent grain and milling yields, low chalk in the kernel, improved plant type, and pest resistance. Through the years, improved disease resistance for rice blast and sheath blight has been a major goal; more recently, bacterial panicle blight has been added to this list. Blast resistance has been addressed by the pathology team, as well as through research by visiting scholars, and graduate students and by the development and release of the cultivars Katy, Kaybonnet, Drew, Ahrent, Templeton, and CL172. Banks was also released from this program with blast resistance, but because blast resistance was derived from backcrossing, it did not contain the minor genes needed to protect it from *IE-1k* in the field. These cultivars are among the first to have resistance to all of the common southern U.S. rice blast races. These first blast resistant cultivars released were susceptible to *IE-1k*, but they had field resistance, which kept the disease at bay. Templeton, one of the more recently released blast resistant cultivars has resistance to the race *IE-1k*. Furthermore, many of the experimental lines in the Arkansas rice breeding program have the gene *Pi-ta* which provides resistance to most southern blast ecotypes and some of these also have resistance to *IE-1k*. Sheath blight tolerance has been an ongoing concern and the cultivars from this program have also had the best sheath blight tolerance of any in the U.S. Rough rice grain yield has become one of the most important characteristics in the last few years and significant yield increases have been realized with the release of the long-grain cultivars LaGrue, Wells, Francis, Banks, Taggart, Roy J, LaKast, and Diamond.

Procedures

The rice breeding program continues to utilize the best available parental material from the U.S. breeding programs, the USDA World Collection, and the International Centers, the International Center for Tropical Agriculture (CIAT), the International Rice Research Institute (IRRI), and the West Africa Rice Development Association (WARDA). Crosses are made yearly to improve grain yield and to incorporate genes for broad-based disease resistance, improved plant type (i.e. short-stature, shorter maturity, erect leaves), superior quality (i.e. low chalk, cooking, processing and eating), and nitrogen (N)-fertilizer use efficiency into highly productive well-adapted lines. The winter nursery in Puerto Rico is utilized to accelerate head row and breeders seed increases of promising lines, and to advance early generation selections each year. As outstanding lines are selected and advanced, they are evaluated extensively for yield, milling, chalk, and cooking characteristics, insect tolerance (entomology group), and disease resistance (pathology group). Advanced lines are evaluated for N-fertilization recommendations, which include the proper timing and rate of N-fertilizer (soil fertility group), and for weed control practices (weed scientists).

The rice breeding program utilizes all feasible breeding techniques and methods including hybridization, backcrossing, marker-assisted selection, mutation breeding, and biotechnology (gene editing in the future) to produce breeding material and new cultivars. Segregating populations and advanced lines are evaluated for grain and milling yields, quality traits, maturity, plant height and type, disease and insect resistance, and in some cases cold tolerance. The statewide rice performance testing program, which includes rice varieties and promising new lines developed in the Arkansas program and from cooperating programs in the other rice-producing states, is conducted each year by the rice extension agronomist. These trials contribute to the selection of the best materials for future release and to provide producers with current information on rice variety performance. Disease data are collected from ongoing inoculated disease plots, which are inoculated with sheath blight, blast and bacterial panicle blight; general observation tests, which are planted in fields with historically high incidences of disease; and general observations which are made during the agronomic testing of entries.

Results and Discussion

Diamond, released to seed growers in 2016, is a very high-yielding, short-season, long-grain line. Diamond originated from the cross, no. 20082221, between Francis and Roy J. It had excellent yields during the hot growing season of 2016, when it yielded 188 bushels (bu)/acre compared to Roy J and LaKast at 167 and 182 bu/acre, respectively. The yield of Diamond for the 2014-2016 Arkansas Rice Performance Trials (ARPT) was 197 bu/acre compared to Roy J, Lakast, Wells, and Mermentau at 181, 182, 175, and 167 bu/acre, respectively (Table 1). Diamond not only has a yield advantage over Roy J but it reaches maturity approximately five days earlier. Diamond will be available as registered seed in 2017. Diamond has the desired kernel length of greater than 7 mm at 7.21 mm according to the Riceland Foods Inc. Laboratory. Head rice yield and cooking quality are also comparable to Wells and Roy J, and it has a clear translucent kernel with low chalk (Table 1). Diamond, LaKast, and Wells have moderate lodging resistance ratings. The milling yield of Diamond in the ARPT, 2014-2016 (Table 1) was 59-69 (59% head rice and 69% total rice), compared to LaKast and Wells at 58-70 and 56-70, respectively. Diamond does not carry any major resistance genes for rice blast and is rated to rice blast, similar to LaKast or Wells. It is moderately susceptible to bacterial panicle blight and very susceptible to false smut.

This program has also released a promising Clearfield cultivar, CL172, to BASF which will be available in 2017 through Horizon Ag. This line has Drew, CL161, Katy, Starbonnet, a Drew sister line, Lemont, radiated Bonnet 73, and a Francis sister line in its pedigree. CL172 has superior lodging resistance, the *Pi-ta* gene for blast resistance, which confers resistance to the common races in the southern U.S., and it maintains excellent grain quality with clear translucent kernels that have very little chalk present.

Two aromatic lines that have good yield, plant type, aroma and taste are being considered for release in 2017-2018. More information on these lines can be found in Wisdom et al., 2017.

In 2016, the high nighttime temperatures and rain showers during heading took a toll on rice yields in Arkansas. Selecting germplasm that could better tolerate these conditions was difficult. The Stuttgart Initial Test (SIT), which is grown at two locations, the RREC and the University of Arkansas System Division of Agriculture's Pine Tree Research Station (PTRS) near Colt, Ark., supplied an opportunity to select lines grown under different conditions. At the RREC, the growing conditions included: hot nighttime temperatures and rain during heading; while at PTRS, the conditions were good during heading. Yields were higher at the PTRS but some lines did better at the RREC than others and also did well at PTRS (Table 2). The experimental lines 16/SIT460 and 16/SIT474 yielded 176 and 163 bu/acre, respectively, at the RREC, and 223 and 239 bu/acre, respectively, at the PTRS (Table 2). While line 16/SIT457 yielded only 136 bu/acre at RREC and 247 bu/acre at the PTRS, respectively, and line 16/SIT418 yielded 160 and 182 bu/acre at the RREC and PTRS, respectively. Heading date was similar for all of these lines ranging from 86 to 90 days for 50% heading and both 16/SIT418 and 16/SIT457 heading on the same day at 90 days after emergence.

Crosses have been made for high yield, good quality, improved milling, and disease resistance in various combinations. Crosses were made for both long- and medium-grain conventional and long-grain Clearfield and aromatic lines in 2016. The F_2 populations from these crosses will be evaluated in 2017 and selections will be grown in the winter nursery during the winter of 2017-2018. Currently, we have 4000 F_3 lines growing in Puerto Rico. One or two panicles will be harvested to produce F_4 lines grown at the RREC as P panicle rows in 2017.

Marker-assisted selection continues to be utilized by this program to help select improved lines with specific genes. In this program, molecular markers allow selection of lines which carry genes associated with high yield in the wild species *Orzya rufipogon*, the *Pi-ta* gene for blast resistance and the apparent amylose classes to predict cooking quality (see Boyett et al. 2005 and 2009). In 2017, a line will be grown in the SIT, from the *Oryza rufipogon* crosses that had the highest yield in the preliminary test in 2016. Additionally, this program is conducting research to identify molecular markers linked to quality traits. These markers will enable breeders to select for high milling quality in early breeding generations. The data derived from this project improves our accuracy and efficiency in choosing parents and advancing lines.

Significance of Findings

The goal of the rice breeding program is to develop maximum yielding cultivars with excellent quality and good levels of disease resistance for release to Arkansas rice producers. The release of Taggart, Templeton, Roy J, LaKast and most recently Diamond demonstrates that continued improvement in rice cultivars for the producers of Arkansas are achieved through this program. Diamond could potentially be the modern replacement for Wells. Improved lines will continue to be released from this program in the future. New cultivars will have the characteristics of improved: yield, disease resistance, plant type, rough-rice grain and milling yields, low chalk, the desired larger kernel size, and overall grain quality. In the future, new rice varieties will be released not only for the traditional southern U.S. long- and medium-grain markets but also for specialty markets that have emerged in recent years

Acknowledgments

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Table 1. Three-year average 2014-2016 Arkansas Rice Performance Trials for Diamond and other cultivars.

Cultivar	Grain type[a]	Yield[b] 2014	2015	2016	Mean	Height	50% Heading	Chalky kernels[c]	Milling
		----------(bu/acre)			----------	(in.)	(days)		(HR:TOT[d])
Diamond	L	218	186	188	197	41	83	1.23	59:69
LaKast	L	202	162	182	182	42	81	1.30	58:70
Mermentau	L	181	161	159	167	38	82	2.05	62:70
Roy J	L	207	169	167	181	41	87	1.35	59:70
Taggart	L	200	167	179	182	43	86	1.29	55:70
Wells	L	192	161	171	175	41	84	1.46	56:70
RTXL753[e]	L	259	212	231	234	44	79	2.68	52:69
RTCLXL745[f]	L	--	187	192	190	44	78	2.22	52:69
CL172	L	--	142	161	152	37	81	1.69	54:69
CL111	L	--	144	149	147	39	80	2.49	60:69
CL151	L	--	166	164	165	39	81	2.72	57:70
CL153	L	--	154	169	161	39	81	1.57	59:69

[a] Grain type L = long-grain.

[b] Yield trials in 2014 and 2015 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, (CC), Corning, Ark.; and Desha County Farmer Field (DC); and in 2016 the trials were conducted at the RREC, PTRS, NEREC, Newport Extension Center, (NEC) and CC.

[c] Data for chalk is from 2013-2015 Riceland Grain Quality Laboratory data; only 2015 data for Cleafield lines.

[d] HR:TOT = head rice : total milled rice 2014-2016, except Clearfield line 2015- 2016.

[e] RT = RiceTec.

[f] CL = Clearfield lines. Chalk data for Clearfield lines is only from 2015.

Table 2. Data from the 2016 Stuttgart Initial Test grown at two locations showing promising long-grain experimental lines and check cultivars.

	Yield[b]			50% Heading		Height		CUP weight[c]	
Cultivar[a]	RREC	PTRS	Mean	RREC	PTRS	RREC	PTRS	RREC	PTRS
	(bu/acre)			(days)		(inches)		(lb/bu)	
Diamond	176	214	195	87	94	46	48	36	43
LaKast	157	214	186	82	94	44	44	33	43
RTXL753a	198	274	236	82	89	47	43	36	41
16/SIT418	160	182	171	90	99	46	46	36	42
16/SIT457	136	247	191	90	100	49	49	33	43
16/SIT460	176	223	199	86	95	45	46	36	43
16/SIT463	135	226	181	88	96	43	44	--	43
16/SIT474	163	239	201	87	97	45	43	35	45
16/SIT521	179	211	195	93	100	43	43	37	45

[a] RT stands for RiceTec, SIT = experimental lines not for sale.

[b] Yield trials in 2016 consisted of two locations: Rice Research and Extension Center (RREC), Stuttgart Ark.; and Pine Tree Research Station (PTRS), Colt, Ark.

[c] CUP weight = a non-metric unit of mass defined as 45 lb/bu for rice.

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- 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 an important component of Arkansas rice. Arkansas ranks second in medium-grain rice production in the United States only behind California. During 2006-2015, an average of 0.17 million acres of medium-grain rice was grown annually, which makes up about 13% of total state rice acreage (USDA-ERS, 2016). 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 Clearfield (CL) 151, CL153, and Mermentau. However, locally devel-

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oped semi-dwarf varieties offer advantages including better stress tolerance and more stable yields. Improved semi-dwarf long-grain lines can be also directly adopted by the newly 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 in overcoming such constraints.

Procedures

Potential parents for the breeding program are evaluated for the desired traits. Cross combinations are programmed that combine desired characteristics to fulfill the breeding objectives. Marker-assisted selection will be carried out on backcross or top-cross 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) near 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. Small size milling sample, as well as the physicochemical analysis at the USDA Rice Quality Lab at 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 to maintain standard U.S. rice quality of different grain types. Yield evaluations include the Stuttgart Initial Test (SIT) and Clearfield SIT (CSIT) at the RREC; the Advanced Elite Line Yield Trial (AYT) at the RREC, the University of Arkansas System Division of Agriculture's Pine Tree Research Station (PTRS) near Colt, Ark., and the Northeast Research and Extension Center (NEREC) in 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 2016 included 646 transplanted F_1 populations, 700 space-planted F_2 populations, and 58,640 panicle rows ranging from F_3 to F_6. Visual selection on approximate 700,000 individual space-planted F_2 plants resulted in a total of 35,000 panicles, which will be individually processed and grown as F_3 panicle rows in 2017. From 58,640 panicle rows, 4500 were selected for advancement to next generation, while 1500 rows appeared to be uniform and superior to others, and therefore were bulk-harvested as candidates for the 2017 SIT or CSIT trials. In the 2016 Clearfield preliminary yield trial (CSIT), 541 new breeding lines were evaluated which included 451 semi-dwarf CL long-grain and 90 CL medium-grain lines. In the SIT trial, 489 new semi-dwarf breeding lines were tested, which consist of 293 long-grain and 196 medium-grain lines. A 60-entry Advanced Elite Line Yield Trial was conducted at the NEREC and the PTRS in addition to the RREC. A number of breeding lines showed yield potential similar to or better than the check varieties (Tables 1-4). Twenty-five advanced breeding lines were evaluated in the multi-state URRN and/or statewide ARPT trials. Results of those entries and selected check varieties are listed in Table 5. Three Puerto Rico winter nurseries of 12,500 rows were planted, selected, harvested and/or advanced throughout 2016. A total of 691 new crosses were made to incorporate desirable traits from multiple sources into adapted Arkansas rice genotypes, which included 257 CL long-grain, 103 CL medium-grain, 118 semi-dwarf conventional long-grain, 92 conventional medium-grain, as well as 91 hybrid test crosses and 18 hybrid backcrosses.

The conventional medium-grain variety Titan was released in the early spring, and the registered seed should be readily available in 2017. Titan matures about six days earlier than Jupiter and has excellent yield potential, good milling and grain quality, and improved blast resistance. Semi-dwarf CL long-grain lines 16AR1111 (RU1601111), 16AR1133 (RU1601133), and 15AR1024 (RU1501024), CL medium-grain line 16AR1030 (RU1601030), and conventional semi-dwarf long-grain line 16AR1124 (RU1601124) were selected for purification and increase in Lajas, Puerto Rico in winter 2016 for their superior yielding potential and excellent milling and grain quality. One hundred thirty-three breeding lines that outperformed commercial check varieties in AYT, CSIT, and SIT trials were selected and are being further evaluated in the laboratory before entering 2017 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.

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Table 1. Performance of selected Clearfield long-grain experimental lines and check varieties in the Clearfield Stuttgart Initial Test (CSIT) at the Rice Research and Extension Center near Stuttgart, Ark., 2016.

Variety/Line	Pedigree	Seedling vigor[a]	Days to 50% heading	Plant height	Yield	Milling yields: Head rice	Milling yields: Total rice
				(cm)	(bu/acre)	----------- (%) ----------	
16CSIT420	RU1102192/4/9502008A//AR1188/CCDR/3/CFX-29/…	3.5	79	105	194	58.0	67.4
16CSIT423	RU1102192/RU1202088	3.5	79	107	192	52.3	63.3
16CSIT438	WLLS/CL161//DREW/CL161/3/RU1102034	3.5	81	111	190	54.6	65.4
16CSIT350	RU1202082/RU1202131	3.0	82	99	187	55.7	61.8
16CSIT125	RU1002128/RU1202097	4.0	80	111	185	64.4	70.8
16CSIT426	RU1102192/RU1202097	3.0	80	95	185	60.8	68.5
16CSIT252	RU1202094/RU0902088	3.5	80	113	184	61.3	65.6
16CSIT440	CCDR/CLR11//CFX-26/9702128/3/RU1102034	4.0	79	104	184	63.0	70.3
16CSIT378	RU1202097/RU1202088	3.5	80	103	184	56.7	62.5
16CSIT437	WLLS/CL161//DREW/CL161/4/CFX-26/9702128/3/…	3.5	80	108	183	60.1	69.4
16CSIT446	RU1102034/RU1302045	3.0	82	114	182	60.6	67.4
16CSIT513	MRMT/RU1401044	3.0	79	103	182	60.3	67.0
CL151	CL151	3.0	81	103	185	60.5	69.6
CL153	CL153	3.0	83	110	185	62.1	68.7
CL172	CL172	3.0	84	96	132	51.3	57.5

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

Table 2. Performance of selected Clearfield medium-grain experimental lines and check varieties in the Clearfield Stuttgart Initial Test (CSIT) at the Rice Research and Extension Center near Stuttgart, Ark., 2016.

Variety/Line	Pedigree	Seedling vigor[a]	Days to 50% heading	Plant height	Yield	Milling yields	
						Head rice	Total rice
				(cm)	(bu/acre)	----------- (%) ----------	
16CSIT508	RU1202065/JPTR	4.0	78	108	195	58.0	65.1
16CSIT246	RU1202168/JPTR	3.0	82	113	188	59.7	63.2
16CSIT463	JPTR/RU1202168	4.0	80	105	186	59.7	64.8
16CSIT213	EARL/9902028//RU1202068	4.0	83	102	186	43.1	62.9
16CSIT279	TITN/RU1202168	4.5	84	108	181	57.9	60.8
16CSIT214	EARL/9902028//RU1202068	3.5	81	97	180	40.9	61.7
16CSIT479	TITN//STG07IMI-01-129/JPTR	4.0	79	99	179	57.5	66.8
16CSIT282	RU1202168//9865216DH2/EARL	3.5	82	101	177	52.4	62.1
16CSIT227	9865216DH2/4/ORIN//…/5/RU1202068	3.0	83	100	177	53.6	61.9
16CSIT215	EARL/9902028//RU1202068	3.0	82	92	177	42.4	63.5
16CSIT490	JPTR/STG07IMI-01-129//JPTR	4.0	79	92	175	58.4	62.9
16CSIT245	RU1202168/JPTR	4.0	86	112	174	56.7	61.7
16CSIT280	TITN/RU1202168	4.0	82	94	172	57.5	62.5
CL153	CL153	3.0	83	110	185	62.1	68.7
CL272	CL272	3.0	81	108	162	54.2	63.6

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

Table 3. Performance of selected conventional medium-grain experimental lines and check varieties in the Stuttgart Initial Test (SIT) at the Rice Research and Extension Center near Stuttgart, Ark., 2016.

Variety/Line	Pedigree	Seedling vigor[a]	Days to 50% heading	Plant height	Yield	Milling yields	
						Head rice	Total rice
				(cm)	(bu/acre)	----------- (%) ----------	
16SIT594[b]	JPTR/J062	3.0	87	98	192	64.1	66.8
16SIT586[b]	LFTE*2/Sasanishiki	3.0	76	99	180	63.0	67.4
16SIT673[b]	ORIN/4/BNGL/3/SMARS/MARS//MARS	4.0	85	99	178	61.5	65.6
16SIT875[c]	JPTR/EARL	4.0	76	88	178	59.7	65.9
16SIT600[b]	JPTR/RU1001099	3.5	84	99	178	62.0	65.3
16SIT593[b]	JPTR/J062	3.5	87	99	176	63.5	66.5
16SIT595[b]	JPTR/J062	3.0	86	95	175	66.1	68.4
16SIT607[b]	BNGL/SHORT RICO/4/9502065/3/BNGL//…	3.0	81	97	175	64.4	67.7
16SIT617[b]	RU0801173/JPTR	3.0	80	95	173	62.1	65.9
16SIT663[b]	EARL/4/9502065/3/BNGL//MERC/RICO	3.0	87	95	172	62.9	67.4
16SIT869[c]	JPTR/3/EARL//BNGL/SHORTRICO	4.0	79	94	172	60.1	65.1
16SIT592[b]	JPTR/J062	4.0	86	97	170	61.2	65.1
Jupiter[b]	Jupiter	3.0	86	99	168	63.0	66.0
Titan[b]	Titan	3.5	81	101	208	64.0	67.8
Titan[c]	Titan	4.0	71	97	157	56.9	66.6

[a] A subjective 1-7 rating taken at emergence, 1 = perfect stand and 7 = no stand.
[b] Planted on 4 April.
[c] Planted on 9 May.

Table 4. Performance of selected conventional long-grain experimental lines and check varieties in the Stuttgart Initial Test (SIT) at the Rice Research and Extension Center near Stuttgart, Ark., 2016.

Variety/Line	Pedigree	Seedling vigor[a]	Days to 50% heading	Plant height	Yield	Milling yields: Head rice	Milling yields: Total rice
				(cm)	(bu/acre)	----------- (%)	----------
16SIT563[b]	RU0902028/RU0802031	3.0	82	101	180	62.4	68.4
16SIT550[b]	9502008//KATY/902207x2/3/RU0601004	3.5	82	98	178	57.7	66.7
16SIT692[b]	RU0901121/5/9502008/CPRS/4/NWBT/KATY//9902207x2/3/…	4.0	83	101	174	59.6	67.2
16SIT567[b]	RU1102028/MRMT	3.0	83	99	169	62.1	69.2
16SIT627[b]	CCDR//CCDR/JEFF/3/RU0802031	3.5	82	100	169	62.1	69.1
16SIT543[b]	9502008-A//AR1188/CCDR/3/CPRS/KBNT//9502008-A/4/…	3.5	81	103	164	57.4	65.7
16SIT566[b]	RU1102028/MRMT	3.0	84	98	162	59.3	67.0
16SIT630[b]	9502008-A//AR1188/CCDR/3/CPRS/KBNT//9502008-A/4/…	3.5	84	102	160	61.0	67.6
16SIT947[c]	RU1002128/LKST	3.0	71	121	160	55.5	66.8
16SIT534[b]	CCDR/JEFF/3/9502008//AR1142/MBLE/4/RU1002195	3.0	84	110	159	59.8	67.8
16SIT551[b]	CHNR/RU0902137	3.0	84	107	159	62.1	69.9
Cheniere[b]	Cheniere	3.0	85	99	140	64.8	71.1
Diamond[b]	Diamond	3.0	85	110	178	58.1	66.5
LaKast[b]	LaKast	4.0	84	111	190	53.7	65.9
LaKast[c]	LaKast	4.0	70	114	173	56.2	69.7
Roy J[b]	Roy J	4.0	91	113	146	56.5	67.2

[a] A subjective 1-7 rating taken at emergence, 1 = perfect stand and 7 = no stand.
[b] Planted on 4 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, 2016.

Variety/Line	Pedigree	Grain type[a]	Days to 50% heading	Plant height	Yield	Milling yields: Head rice	Milling yields: Total rice
				(cm)	(bu/acre)	----------- (%) ----------	
RU1601030	RU1202168/JPTR	CM	88	108	184	62.6	68.3
RU1601050	RU1301124/CL261	CM	83	104	182	60.0	69.1
RU1601133	RU1102192/4/WLLS/CFX-18/3/CFX-18//CCDR/9770532 DH2	CL	85	109	181	63.5	70.1
RU1601027	BNGL//ORIN/BNGL	M	85	98	178	63.2	69.0
RU1501024	CL111/3/CCDR//9502008/LGRU	CL	82	103	178	63.1	70.7
RU1501111	BNGL/CL161/4/9502065/3/MERC//MERC/…	CM	85	103	175	65.2	70.8
RU1601167	RU1302045/CL111	CL	81	108	172	62.7	69.3
RU1601099	RU0502068/RU1202088	CL	82	105	171	62.4	69.9
RU1601121	CTHL/RU1002192	L	81	101	167	61.5	71.6
Jupiter	Jupiter	M	85	96	180	64.2	68.4
Titan	Titan	M	82	97	182	63.6	69.6
CL153	CL153	CL	81	101	187	62.1	69.8
CL172	CL172	CL	82	96	149	60.3	68.9
CL272	CL272	CM	82	100	167	59.9	68.1
LaKast	LaKast	L	81	108	199	54.6	71.2
Diamond	Diamond	L	83	105	193	55.4	69.9

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

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

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Abstract

A controlled yield trial conducted in the most representative soil and environmental conditions is critical for rice breeders to identify the ideal genotypes for potential varietal releases. An Advanced Elite Line Yield Trial (AYT) is conducted at three locations in Arkansas to bridge the gap between the single location, two replication preliminary yield trials and the multi-state Uniform Regional Rice Nursery (URRN) and/or the multi-location statewide Arkansas Rice Performance Trials (ARPT) which only accommodate a very limited number of entries. The AYT composed 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), near 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 in the selection of the best and the most uniform breeding lines for advancement into the URRN and/or ARPT trials, and ultimately improving the quality of those yield trials.

Introduction

Complicated rice traits, such as yield and quality can only be evaluated effectively in replicated plots. Once rice breeding lines with desired characteristics are reasonably uniform, they are bulk-harvested and tested in the single location, 2-replication preliminary yield trials, which include the Clearfield Stuttgart Initial Test (CSIT) or Stuttgart Initial Test (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, multi-location advanced yield trials. However, the current advanced yield

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trials include the multi-state Uniform Regional Rice Nursery (URRN) and statewide Arkansas Rice Performance Trial (ARPT) that only accommodate about 20 entries from each breeder each year. Obviously, 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 the URRN and ARPT trials.

Procedures

A total of 60 entries were tested in the 2016 Advanced Elite Line Yield Trial (AYT), which included 48 experimental lines (24 Clearfield long-grain, 4 Clearfield medium-grain, 7 semi-dwarf long-grain, and 13 medium-grain), and 12 commercial check varieties. Nineteen of the experimental lines were also concurrently tested in 2016 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 (8 rows with a 7.5-inch row spacing) and 14 ft long were drill-seeded at a 75 lb/acre rate. The soil types at the University of Arkansas System Division of Agriculture's Northeast Research and Extension Center, (NEREC), in Keiser, Ark.; the Pine Tree Research Station, (PTRS), near Colt, Ark.; and the Rice Research and Extension Center, (RREC), near Stuttgart, Ark., are Sharkey clay, Calloway silt loam, and DeWitt silt loam, respectively. Planting dates at NEREC, PTRS, and RREC were 19 April, 15 April, and 4 April, respectively. A single preflood application of 150 pounds (lb) of nitrogen (N) in the form of urea was applied to a dry soil surface at the 4- to 5-lf stage, and a permanent flood was established 1 to 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 determinations. 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, version 9.4 (SAS Institute, 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 166 bushel per acre (bu/acre) (Table 1), which is 19 bu/acre (10.2%) lower than that of 2015. Among 3 locations, NEREC has the highest yield of 181 bu/acre, followed by PTRS at 176 bu/acre, and RREC had the lowest yield of 142 bu/acre, which may be attributed to the combination of extreme high nighttime temperature and bacterial panicle blight. Overall, medium-grain rice performed better than long-grain rice. The top 5 high-yielders are all medium-grain rice, and include 16AYT060, 16AYT031, 16AYT029, Titan, and 16AYT054 with the average grain yield of 203, 202, 199, 196, and 194 bu/acre, respectively (Table 1). Milling yields are lower than that of 2015. The average head rice and total rice of three locations are 63.4% and 66.8%, respectively, which are 3.4% and 3.8% lower than that of 2015, respectively. RREC has the lowest milling yields among the three locations (Table 2). The average seedling vigor is 3.6, which is better than that of 2015, the average days to 50% heading is 89 days, and the average plant height is 41 inches (Table 2).

Among Clearfield long-grain lines, 16AYT045 and 16AYT016 (RU1601133) had a numerically higher grain yield than check CL151 and/or CL153 (Table 1), while all four Clearfield medium-grain lines, 16AYT041, 16AYT049, 16AYT017 (RU1601136), and 16AYT026 had either a statistically or numerically higher grain yield than check CL272. Three conventional medium-grain lines 16AYT060, 16AYT031, 16AYT029 had a numerically higher grain yield than either Titan or Jupiter. All conventional long-grain lines yielded lower than check variety LaKast or Diamond that has the conventional height; however, five conventional long-grain lines (16AYT051, 16AYT013, 16AYT053, 16AYT052, and16AYT050) had a numerically higher grain yield than the semi-dwarf check Mermentau. Some of these lines were selected for purification and increase in the winter nursery in Lajas, Puerto Rico during the winter of 2016.

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 that 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 otherwise 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 elite line yield trial (AYT) conducted at University of Arkansas System Division of Agriculture's Northeast Research and Extension Center (NEREC) at Keiser, Ark., Pine Tree Research Station (PTRS) near Colt, Ark., and Rice Research and Extension Center (RREC) near Stuttgart, Ark., 2016.

Entry	Pedigree	Grain type[a]	Grain yield NEREC	Grain yield PTRS	Grain yield RREC	Grain yield Mean
			(bu/acre)			
16AYT001	CL111	CL	160	167	154	161
16AYT002	CL151	CL	183	182	144	170
16AYT003	CL153	CL	181	190	129	167
16AYT004	CL163	CL	164	144	142	150
16AYT005	CL172	CL	177	170	118	155
16AYT006	CL272	CM	183	186	112	160
16AYT007	Mermentau	L	174	147	121	147
16AYT008	LaKast	L	199	188	191	193
16AYT009	Diamond	L	202	183	166	184
16AYT010	Roy J	L	175	178	145	166
16AYT011	Jupiter	M	205	183	167	185
16AYT012	Titan	M	204	208	177	196
16AYT013	CYBT/LM1/4/WLLS/PI597049/3/RSMT//NWBT/KATY/5/9901133/JEFF	L	177	168	123	156
16AYT014	RU1102034/RU1202082	CL	168	161	118	149
16AYT015	CL172/5/CPRS/NWBT//KATY/3/CCDR/4/CFX-18//CCDR/9770532 DH2	CL	178	169	143	163
16AYT016	RU1102192/4/WLLS/CFX-18/3/CFX-18//CCDR/9770532 DH2	CL	197	175	137	170
16AYT017	RU1202168//RU0602162/RU0502031	CM	192	196	127	172
16AYT018	RU1102034/RU1302045	CL	171	175	116	154
16AYT019	RU1302045/CL111	CL	175	173	131	160
16AYT020	STG10IMI-05-034//RU0902155/RU0902131	CL	181	179	120	160
16AYT021	RU1302045/MRMT	CL	174	172	125	157
16AYT022	RU1302048/RU1302045	CL	175	173	143	164
16AYT023	CCDR//CCDR/JEFF/3/CL131/4/RU1302045	CL	158	177	130	155
16AYT024	RU0902034/RU0502068	L	153	150	119	141
16AYT025	JPTR/RU1001099	M	189	175	177	180
16AYT026	CFFY/RU1202168	CM	182	182	123	162

continued

Table 1. Continued.

Entry	Pedigree	Grain type[a]	Grain yield NEREC	PTRS	RREC	Mean
			---- (bu/acre) ----			
16AYT027	BNGL/SHORT RICO/4/9502065/3/BNGL//MERC/RICO	M	181	186	152	173
16AYT028	EARL/9902028//RICO/BNGL	M	217	220	138	192
16AYT029	EARL/9902028//JPTR	M	216	204	175	199
16AYT030	EARL/9902028//JPTR	M	194	194	171	186
16AYT031	JPTR/TITN	M	211	206	188	202
16AYT032	RU1102028/CL111	CL	161	166	149	159
16AYT033	CCDR/CPRS	L	154	149	124	142
16AYT034	WLLS/CFX-18/3/CFX-18//CCDR/9770532 DH2	CL	187	178	110	159
16AYT035	RU1002128/4/9502008-A//AR1188/CCDR/3/CFX-29//AR1142/LA2031	CL	165	175	154	165
16AYT036	RU1102034/4/CCDR/JEFF/3/CFX-18//CCDR/9770532 DH2	CL	169	154	113	145
16AYT037	RU1102034/4/CCDR/JEFF/3/CFX-18//CCDR/9770532 DH2	CL	152	150	124	142
16AYT038	CCDR/JEFF//CFX-18//CCDR/9770532 DH2	CL	153	165	104	141
16AYT039	CL172/RU1202094	CL	173	169	119	154
16AYT040	CL172/RU1102192	CL	171	157	158	162
16AYT041	RU1202065/JPTR	CM	188	194	151	178
16AYT042	RU1102034/RU1302045	CL	171	169	121	154
16AYT043	RU1102034/RU1302045	CL	177	184	132	164
16AYT044	MRMT/STG10IMI-02-186	CL	174	164	149	162
16AYT045	RU1202051/ROYJ	CL	186	174	161	174
16AYT046	RU1102028/CL111	CL	168	161	147	159
16AYT047	RU1302045/MRMT	CL	169	173	129	157
16AYT048	RU1302045/FRNS	CL	170	177	122	156
16AYT049	RU1202068/TITN	CM	179	174	165	173
16AYT050	RU0502068/RU1002128	L	173	151	135	153
16AYT051	CCDR/CHNR	L	169	160	145	158
16AYT052	CCDR/JEFF/3/9502008//AR1142/MBLE/4/RU1102034	L	167	158	134	153
16AYT053	CHNR/CTHL	L	185	157	124	155
16AYT054	JPTR/J062	M	213	196	173	194
16AYT055	JPTR/RU0401136/3/RU9901127/97Y228//RU0101090/UA99-128/4/…	M	173	181	168	174

continued

Table 1. Continued.

Entry	Pedigree	Grain type[a]	Grain yield NEREC	PTRS	RREC	Mean
16AYT056	CFFY/JPTR	M	197	178	160	178
16AYT057	EARL/9902028//RICO/BNGL	M	201	203	162	188
16AYT058	EARL/9902028//RICO/BNGL	M	212	192	164	189
16AYT059	EARL/9902028//CFFY	M	210	175	117	167
16AYT060	JPTR/TITN	M	203	220	186	203
c.v. (%)[b]			5.5	5.4	6.3	6.0
$LSD_{0.05}$			16	15	14	9

[a] Grain type, CL = Clearfield long-grain, CM = Clearfield medium-grain, L = conventional long-grain, and M = conventional medium-grain.
[b] c.v. = coefficient of variance.

Table 2. Average seedling vigor, days to 50% heading, plant height, and milling yields of the 2016 Advanced Yield Trial (AYT) conducted at the University of Arkansas System Division of Agriculture's Northeast Research and Extension Center (NEREC) at Keiser, Ark.; Pine Tree Research Station (PTRS) near Colt, Ark.; and Rice Research and Extension Center (RREC) near Stuttgart, Ark.

Entry	Pedigree	Grain Type[a]	Seedling Vigor[b]	Days to 50% Heading	Height	Milling Yield[c]
					(inches)	
16AYT001	CL111	CL	3.0	85	40	65-68
16AYT002	CL151	CL	3.0	87	40	65-68
16AYT003	CL153	CL	3.0	89	41	62-65
16AYT004	CL163	CL	3.0	94	41	62-65
16AYT005	CL172	CL	3.2	91	40	61-65
16AYT006	CL272	CM	3.6	86	41	64-67
16AYT007	Mermentau	L	3.0	90	40	62-66
16AYT008	LaKast	L	3.3	87	43	64-69
16AYT009	Diamond	L	3.3	91	42	61-66
16AYT010	Roy J	L	3.2	97	43	59-65
16AYT011	Jupiter	M	3.4	90	38	67-69
16AYT012	Titan	M	3.3	83	38	67-70
16AYT013	CYBT/LM1/4/WLLS/PI597049/3/RSMT//NWBT/KATY/5/9901133/JEFF	L	3.9	89	40	64-67
16AYT014	RU1102034/RU1202082	CL	3.7	91	43	63-66
16AYT015	CL172/5/CPRS/NWBT//KATY/3/CCDR/4/CFX-18//CCDR/9770532 DH2	CL	4.0	92	41	62-65
16AYT016	RU1102192/4/WLLS/CFX-18/3/CFX-18//CCDR/9770532 DH2	CL	3.8	90	44	63-67
16AYT017	RU1202168//RU0602162/RU0502031	CM	3.7	92	40	66-69
16AYT018	RU1102034/RU1302045	CL	3.4	92	42	61-65
16AYT019	RU1302045/CL111	CL	3.3	89	43	62-65
16AYT020	STG10IMI-05-034//RU0902155/RU0902131	CL	3.7	89	41	61-66
16AYT021	RU1302045/MRMT	CL	3.2	92	42	61-65
16AYT022	RU1302048/RU1302045	CL	3.2	86	41	61-65
16AYT023	CCDR//CCDR/JEFF/3/CL131/4/RU1302045	CL	3.1	88	43	62-66
16AYT024	RU0902034/RU0502068	L	3.7	91	41	61-65
16AYT025	JPTR/RU1001099	M	3.4	89	40	67-69
16AYT026	CFFY/RU1202168	CM	3.9	92	41	64-67
16AYT027	BNGL/SHORT RICO/4/9502065/3/BNGL//MERC/RICO	M	3.7	88	40	67-69

continued

Table 2. Continued.

Entry	Pedigree	Grain Type[a]	Seedling Vigor[b]	Days to 50% Heading	Height	Milling Yield[c]
					(inches)	
16AYT028	EARL/9902028//RICO/BNGL	M	3.3	86	38	65-68
16AYT029	EARL/9902028//JPTR	M	3.7	89	39	65-68
16AYT030	EARL/9902028//JPTR	M	3.2	86	37	66-69
16AYT031	JPTR/TITN	M	3.7	83	39	67-69
16AYT032	RU1102028/CL111	CL	3.4	87	40	64-68
16AYT033	CCDR/CPRS	L	3.3	91	41	62-65
16AYT034	WLLS/CFX-18/3/CFX-18//CCDR/9770532 DH2	CL	3.8	92	43	62-65
16AYT035	RU1002128/4/9502008-A//AR1188/CCDR/3/CFX-29//AR1142/LA2031	CL	3.9	84	43	63-67
16AYT036	RU1102034/4/CCDR/JEFF/3/CFX-18//CCDR/9770532 DH2	CL	4.0	89	43	62-65
16AYT037	RU1102034/4/CCDR/JEFF/3/CFX-18//CCDR/9770532 DH2	CL	3.7	90	43	61-65
16AYT038	CCDR/JEFF//CFX-18//CCDR/9770532 DH2	CL	4.1	90	43	58-63
16AYT039	CL172/RU1202094	CL	4.7	88	43	62-65
16AYT040	CL172/RU1102192	CL	4.3	86	43	64-67
16AYT041	RU1202065/JPTR	CM	3.8	87	40	66-69
16AYT042	RU1102034/RU1302045	CL	3.8	92	42	63-66
16AYT043	RU1102034/RU1302045	CL	3.4	90	42	63-66
16AYT044	MRMT/STG10IMI-02-186	CL	3.4	90	40	65-67
16AYT045	RU1202051/ROYJ	CL	3.9	91	36	62-67
16AYT046	RU1102028/CL111	CL	3.8	88	41	64-68
16AYT047	RU1302045/MRMT	CL	3.6	93	42	65-70
16AYT048	RU1302045/FRNS	CL	3.6	87	40	61-71
16AYT049	RU1202068/TITN	CM	3.6	85	41	64-68
16AYT050	RU0502068/RU1002128	L	3.2	93	42	61-66
16AYT051	CCDR/CHNR	L	3.4	86	43	63-67
16AYT052	CCDR/JEFF/3/9502008//AR1142/MBLE/4/RU1102034	L	3.3	89	42	64-67
16AYT053	CHNR/CTHL	L	3.3	93	41	62-66
16AYT054	JPTR/J062	M	3.7	90	39	66-68
16AYT055	JPTR/RU0401136/3/RU9901127/97Y228//RU0101090/UA99-128/4/BNGL	M	3.2	85	38	62-68
16AYT056	CFFY/JPTR	M	4.2	88	42	66-69

continued

Table 2. Continued.

Entry	Pedigree	Grain Type[a]	Seedling Vigor[b]	Days to 50% Heading	Height	Milling Yield[c]
					(inches)	
16AYT057	EARL/9902028//RICO/BNGL	M	3.9	86	41	65-68
16AYT058	EARL/9902028//RICO/BNGL	M	3.6	88	41	65-68
16AYT059	EARL/9902028//CFFY	M	4.3	89	40	66-67
16AYT060	JPTR/TITN	M	4.1	84	38	68-70
c.v. (%)[d]			12.2	2.4	4.4	2-2
$LSD_{0.05}$			0.4	2	2	1-1

[a] Grain type, CL = Clearfield long-grain, CM = Clearfield medium-grain, L = conventional long-grain, and M = conventional medium-grain.
[b] A subjective rating 1-7 taken at emergence, 1 = excellent stand and 7 = no stand.
[c] Milling yield = % head rice / % total rice.
[d] c.v. = coefficient of variance.

Progress in Development of Male-Sterile Lines for Hybrid Rice

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Abstract

The University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC) is committed to developing new hybrid rice cultivars with high seed yield and good milling and eating quality through extensive field and greenhouse studies. We utilize advanced genetic molecular techniques such as marker-assisted selection (MAS) in the hybrid breeding program. In 2016 our efforts were to 1) evaluate the male-sterile, maintainer (B), and restorer (R) lines developed in Arkansas for their cooking quality and phenotypic characteristics; 2) evaluate and advance several environmental genic male-sterile (EGMS) lines utilized for the two-line hybrid system; 3) initiate the development of new EGMS lines and new cytoplasmic male-sterile (CMS) lines, B lines, and R lines for application in the three-line hybrid rice system; and 4) cross Arkansas male-sterile lines with several Arkansas elite cultivars to evaluate yield performance and eating quality of potential hybrid lines.

Introduction

Demand for production of hybrid rice in Arkansas has increased rapidly in the last decade due to its yield performance and durable resistance/tolerance to biotic and abiotic stresses (Lyman and Nalley, 2013). A study showed that 32 newly released hybrid cultivars outperformed a conventional high-yielding cultivar Francis by up to 30.7% (Huang and Yan, 2016).

Hybrid rice is commercially grown F_1 seed resulting from a cross between two genetically diverse parents (Virmani et al., 2003). This technology requires a male-sterile line assigned as the female parent and a pollen fertile parent assigned as the male parent. The F_1 plants resulting from such hybridization demonstrate higher yield compared to its parents due to a phenomenon known as "Heterosis". Higher seed yield is the foremost goal in hybrid rice production. Several studies showed that heterosis effectively influ-

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ences several yield components such as panicle number and spikelet number (Amandakumar and Sreehangasamy, 1984; Chang et a1., 1971, 1973; Devarathinam 1984).

Grain quality of hybrid rice is another important factor in hybrid rice breeding. Grain quality should meet all consumer and producer requirements including milling and head rice recovery, seed appearance, and cooking and eating characteristics (Khush et al., 1988; Tan et al., 2000). Chalkiness reduces milling quality, yield, and the seed marketability as a result. Factors that influence seed appearance are chalkiness, grain size (short-, medium-, or long-grain), seed shape, and uniformity (Khush et al., 1988). The eating quality is determined generally by seed amylose content, gelatinization temperature, gel consistency, and aroma.

Improving tolerance/resistance to environmental stresses is another key factor in hybrid rice breeding. One practical strategy is to identify the genetic sources of resistance/tolerance to biotic and abiotic stresses in rice germplasm and integrate those genes into the genome of male-sterile lines.

The steps in the process of hybrid rice breeding include 1) developing male-sterile lines, B and R lines; 2) synchronization of flowering between male-sterile lines and elite cultivars assigned as male parents; 3) measuring heterosis via comparing hybrid performance with the reference variety and parental line; and 3) developing field management strategies to increase yield and improve eating quality in hybrid rice (Virmani and Sharma, 1993; Virmani et al., 2003; Yuan and Virmani,1988).

The idiotype male-sterile line should be completely sterile, semi-dwarf, long-grain, non-aromatic with intermediate amylose content and gelatinization temperature, and be disease resistant. The most common types of male-sterile lines in hybrid rice breeding are the cytoplasmic male-sterile (CMS) line, which is applied in the three-line system, and the environmental genic male-sterile (EGMS) line assigned for the two-line system (Virmani et al., 1997).

It is important for the male-sterile line, which serves as the female parent, to be shorter than the male parent for good pollination, therefore a semi-dwarf line is desirable. The mutation gene *sd1* is associated with semi-dwarf phenotype and is considered one of the important genetic sources in the Green revolution. It is originally derived from "Dee-geo-woo-gen" rice and then was integrated into rice cultivar IR8 (Sasaki et al., 2002).

The male-sterile line needs to have an amylose content between 20-25% (Kush et al., 1988; Patindol et al., 2010) for long-grain rice quality which significantly regulates the texture of cooked rice kernel. Long-grain rice, which is a major type of rice production in the southern region of the United States, is a slender, dry, and fluffy rice, with the grains remaining separated after cooking (Mackill and McKenzie, 2002; Webb et al., 1985). The majority of elite rice cultivars have an intermediate gelatinization that provides an acceptable texture of cooked rice (Cuevas et al., 2010).

There are numbers of major and minor rice diseases in Arkansas such as sheath blight, rice blast, stem rot, and crown sheath rot (Wamishe, 2013). Several resistance genes associated with rice blast disease have been reported and are being detected in Arkansas rice cultivars via molecular studies (Boyett et al., 2016). These will also be considered in the hybrid program.

Procedures

Our aim in 2016 was to:1) propagate seeds from University of Arkansas System Division of Agriculture's male-sterile lines which possess desirable and homogenous agronomic and eating quality characteristics; 2) develop new EGMS lines for two-line hybrid rice systems; 3) develop new CMS lines and their B lines as well as R lines for three-line hybrid rice system; and 4) produce F_1 seeds resulting from crosses between the Division's male-sterile lines and Arkansas elite cultivars.

Seed Increase and Genotypic Evaluation

To propagate seeds from lines with desirable agronomic and eating qualities, several male-sterile and R lines developed at the RREC including two EGMS lines of 811S and 236S, two CMS lines of 341A and 873A and their correspondent B lines, and four R lines of 351R, 367R, 394R, 396R were grown under greenhouse conditions in December 2015. The preliminary studies showed that these lines have good eating quality. After extensive molecular analysis, several plants homozygous for desirable alleles from each line were selected and transferred to a growth chamber for seed increase.

Two-Line System

1. Seeds from 49 BC_1F_3 plants resulting from a cross between 236s, an EGMS line developed at the RREC, and RU1201102 were planted in 49 plots. Previously, these 49 BC_1F_3 plants had been tested and selected based on good cooking quality and several agronomic traits via DNA marker-assisted selection (MAS). Each plot was evaluated based on phenotypic characteristics such as uniformity, heading date, plant height, plant type, number of panicle per plant, stiff straw, overall panicle exertion, and percent of sterility of the primary panicles. A total 190 BC_1F_3 plants were selected, ratooned and placed in a greenhouse in an environmental condition required for seed production for male-sterile plants. The rate of panicle exsertion varied among the selected plants: The panicle exsertion of 62 single plants were > 85%; 62 were 80-85%, and 66 were <85%.
2. To analyze the percentage of cross combination, several BC_1F_3 plants from the plots mentioned above, along with 811s plants, a male-sterile line developed at the RREC, were crossed with Arkansas long-grain cultivars or advanced lines. Overall, there were 35 combinations with 811s and 26 combinations with the BC_1F_3 plants resulting in 61 new hybrid lines. The F_1 (hybrid) seeds were carefully collected from each female (male-sterile) plant. The F_1 seeds (hybrid seeds) along with their male parental lines will be planted in a field condition in 2017 to evaluate hybrid performance.
3. A total of 1047 BC_1F_2 single plants from four populations resulting from crosses between 236s and 811s, designated as female parents, with Francis, Cocodrie, and RU1201102, assigned as male parents, were grown in a field and evaluated via MAS for cooking quality, disease resistance, and plant height, and were evaluated

phenotypically for heading date, plant type, plant height, sterility, and panicle exertion rate. A total of 40 plants were selected, ratooned, and placed in a greenhouse to produce BC_1F_3 seeds for planting in a field condition in summer 2017.

4. We crossed three male-sterile lines of 236s, 805s, and 811s with 17 high-yield, semi-dwarf, and non-aromatic cultivars or advanced lines and collected the F_1 seeds resulting from 33 successful combinations. The F_1 plants will be grown under greenhouse conditions this fall and backcrossed with their correspondent male-sterile parents to get BC_1F_1 seeds. That resulting population will be grown in summer 2017.

Three-Line System

1. We made crosses between 873B line, an Arkansas B line, and 10 Arkansas elite cultivars or advanced lines. The F_1 plants were collected and will be planted in a greenhouse and will be backcrossed with the B line to produce BC_1F_1 seeds. The BC_1F_1 plants will be grown in a field in summer 2017.
2. Four restorer (R) lines of 351R, 367R, 394R, and 396R that possess genes associated with desirable traits were crossed with 39 high yield tall genotypes to develop new R lines. The F_1 plants will be grown in a greenhouse and backcrossed with their correspondent R line to get BC_1F_1 seeds. The BC_1F_1 plants will be grown in a field condition in summer 2017.

Screening RREC Restorer and Male-Sterile Lines

We conducted molecular and phenotypic studies to evaluate and homogenize 14 EGMS and five R lines developed previously by RREC for cooking and agronomic traits. Several EGMS and R plants were selected, and their seeds were bulked. These lines will be used for developing new R and EGMS lines.

Results and Discussion

A total of 49 BC_1F_3 lines were tested for several agronomic characteristics via phenotypic and molecular analysis. Due to high humidity in the late season, an outbreak of false smut damaged panicles in all of the plots, making the selection process harder. We selected single plants that were completely sterile, with erect, semi dwarf plant type, and high stem sturdiness.

All lines possessed alleles associated with desirable cooking qualities. Each plot exhibited relative homogeneity and uniformity for several phenotypic traits such as plant height, heading date, panicle exsertion, and plant type; however, plants in each plot were segregating for sterility. The preliminary observation showed that only a few number of plants exhibited complete sterility, which indicates that recessive genes control the sterility. Previous studies by Shi, 1985; Zhang et al., 1993, 1994, support this assumption.

The heading date varied among BC_1F_3 populations from 81 to 93 days. Synchronization between male-sterile lines and elite cultivars is a crucial step in hybrid production.

Different heading dates of hybrid parental lines causes less chance of cross-pollination and as a result, fewer number of hybrid seeds. To address this issue, we are seeking to develop several male-sterile lines with different ranges of heading dates, so they can perfectly correspond with the selected male parent lines.

Plant height is another important factor in hybrid rice production. Heterosis in plant height is considered an unfavorable phenomenon because it increases the chance of the hybrid (F_1) plants lodging (Chang et al., 1971; Pillai, 1961; Singh and Singh, 1977). To avoid this problem, we are focused on developing semi-dwarf male-sterile plants by integrating the semi-dwarf gene (*sd1*) into the male-sterile genomic background. The ideal male-sterile line should be shorter than the pollen donor plants to improve the chance of cross-pollination; therefore, we selected only those sterile BC_1F_3 plants with heights less than 100 cm.

As expected, there was wide variation in agronomic and eating quality characteristics across the BC_1F_2 populations. Three molecular markers at the *Waxy* locus, *Waxy* Exon 1, *Waxy* Exon 6, and RM190 were applied for amylose content determination. All BC_1F_2 were classified as having either low, intermediate, or high amylose content except the population 236 × Francis, in which all individual plants possessed homozygous alleles associated with low amylose content.

The BC_1F_1 plants were also tested for gelatinization temperature using the *Alk* marker and were grouped into two classes of low and medium to high. Three molecular markers of RM224, *Pi-indica*, and KASP_YL153 were used to assess rice blast disease resistance. The RM224 marker is linked to the *Pi-k* locus. The other two markers are both linked to the *Pi-ta* locus. The majority of single plants were fertile because the male-sterile gene is a recessive gene.

One important part of our program is to develop new R lines because the majority of American rice genotypes, which are *Japonica* cultivars, do not have R genes. To develop *Japonica* type R lines, we crossed Arkansas R lines with Arkansas elite cultivars. The F_1 plants will be backcrossed to their correspondent R parents because the R gene in F_1 plants are in the heterozygous state.

For developing CMS and B lines, we made several crosses between the Division's CMS lines and Arkansas rice cultivars, but these attempts were not successful. Therefore, our strategy for developing CMS and A lines, which is somewhat similar to the R lines is as follows: First, we cross B lines to the elite cultivar, then the F_1 will be backcrossed with B line. The BC_1F_1 plants will be grown and the breeding process will continue until all desirable genes associated with agronomic traits are integrated successfully into the B line genome. Then the improved B line will be crossed with corresponding CMS lines and the process will continue according to the conventional CMS breeding methods.

Significance of Findings

We are in the process of expanding the three-line and two-line hybrid rice production. The BC_1F3 plants showed some promising features and may become the next male EGMS line. Several BC_1F_2 plants possess alleles associated with desirable traits; however, further studies are required for selecting and developing elite male-sterile lines.

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Tissue Culture and Transformation Response of Rice Cultivars Developed in Arkansas Breeding Program

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Abstract

Diverse crop cultivars contain rich genetic resources including useful traits. Transfer of these traits into the adapted cultivars, however, can be complicated by the polygenic nature of the trait and/or the genetic distance. Targeted mutagenesis or gene editing is a novel method of creating genetic variation and introducing useful traits. The gene editing process in most crop species, including rice, relies on the use of totipotent tissue cultures that regenerate healthy plants. Therefore, determining tissue culture potential of the newly developed rice cultivars will be important for implementing gene editing. This study tested the tissue culture response of 20 Arkansas rice cultivars, and found 10 to generate embryogenic cultures that regenerated plants at 18-75% estimated efficiency. A subset of 7 lines was screened for its ability to be transformed by *Agrobacterium* and the Biolistics™ methods. Stable transformations were isolated in all, with Biolistics™, invariably, being ≥2X more effective than *Agrobacterium*. Some of the top Arkansas cultivars, Roy J, Francis, and Taggart, were among top tissue culture and transformation responders.

Introduction

Rice tissue culture is a well-established technique that utilizes mature seeds (embryos) to generate embryogenic callus and regenerate healthy, fertile plants. However, tissue culture response is genotype-dependent, and rice is no exception (Abe and Futsuhara, 1986). The implementation of most biotechnology tools, including gene editing, in crops requires an efficient tissue culture process, which is generally limited to a few model cultivars (Hiei et al., 2014). The top tissue culture cultivars of rice include Nipponbare, Taipei-309, and Kitaake, all of which are 'genetically distant' from the modern cultivars. Targeted mutagenesis by gene editing methods is commonly practiced in these cultivars (Li et al., 2016; Srivastava et al., 2017) but their value to breeding programs is questionable. Direct application of gene editing in the modern cultivars will be highly valuable to breeding programs as the genetic variation created in these cultivars could

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be easily introgressed into the new cultivars. Therefore, it is important to determine tissue culture response and regeneration potential of the Arkansas rice cultivars.

The literature on the tissue culture response of the U.S. rice cultivars is sparse. Al-Khayri et al. (1996) tested tissue culture response of 5 rice cultivars and found commercial cultivars LaGrue and Katy as good tissue culture responders. Dabul et al. (2009) screened 33 rice cultivars, 9 of which were reported as having 50% rate of plant regeneration after 45 days in the media. This study included a broad rice germplasm, including 6 Arkansas rice cultivars. In the present work, a set of 20 rice cultivars, developed in Arkansas, was screened for its tissue culture potential followed by screening on a subset for its ability to be transformed by *Agrobacterium* and Biolistics™ mediated DNA delivery methods.

Procedures

Rice Germplasm

Twenty-one tropical japonica rice cultivars of medium- or long-grain type, developed in the Arkansas rice breeding program, were obtained from Karen Moldenhauer, Professor, University of Arkansas System Division of Agricuture's Rice Research and Extension Center, near Stuttgart, Ark. Two model cultivars, Nipponbare and Kitaake, were included as positive controls (Table 1). The seeds of Arkansas cultivars were derived from field-grown plants and those of the model cultivars from the greenhouse-grown plants at the University of Arkansas System Division of Agriculture's Rosen Center, Fayetteville, Ark.

In Vitro Tissue Culture

The tissue culture protocols described by Nishimura et al (2006) were adopted in this study. Briefly, 50 de-husked seeds of each cultivar were rinsed with 70% ethanol, surface sterilized by 30% commercial bleach for 30 minutes, and washed 3× with sterilized water. The sterilized seeds were soak-dried on autoclaved paper, and plated on 2N6 media consisting of N6 basal media (Chu et al., 1975) at pH 5.8 containing sucrose (30 mg/l), 2,4-D (2 mg/l), and phytagel (3 g /l) for callus induction. The callus response was noted 2 and 4 weeks after plating. Ten regenerated calli were transferred to the regeneration media consisting of MS basal media (Murashige and Skoog, 1962) at pH 5.8, supplemented with Kinetin (2 mg/l), NAA (0.2 mg/l), sucrose (15 g/l), and phytagel (3 g/l). The greening and shooting response was recorded after 4 and 6 weeks, respectively.

Genetic Transformation

Genetic transformation of rice cultivars was tested by two methods, *Agrobacterium*-mediated transformation and Biolistics™ described by Nishimura et al. (2006) and Srivastava (2013), respectively, using *Agrobacterium tumefaciens* strain EHA105 or PDS1000/He gene gun (Bio-Rad, Inc.). The transformation vector used for genetic transformation contained hygromycin phosphotransferase (HPT) gene and green fluorescent protein (GFP) gene for selection on hyrgomycin and visualization of transgenic events, respectively. The callus treated with *Agrobacterium* or Biolistics™ were selected on 2N6 media supplemented with hygromycin (50 mg/l; Invitrogen, Inc.), and the emergence of hygromycin-resistant clones was recorded 4-6 weeks later. The expression of GFP was confirmed by observing green fluorescence under stereomicroscope fitted with SFA Stereo Microscope Fluorescence Adapter system (Nightsea, Inc.)

Results and Discussion

The callus formation, characterized by the growth of a mass of cells from the mature embryo, in the rice cultivars could be observed within 2 weeks (early responders) or as late as after 4 weeks (late responders). The model cultivars, Nipponbare and Kitaake, generated callus within 2 weeks. The early responders, generally, generated embryogenic callus while the late responders generated mixed callus consisting of embryogenic + friable mass. Of 20 rice cultivars, 12 generated embryogenic callus within 2 weeks, while the remaining generated small calli after 4 weeks on the tissue culture media. The morphology of embryogenic callus from a few selected cultivars is shown in Fig. 1a. In comparison to the model cultivars, Nipponbare and Kitaake, that respond at 100% rate, the callus response of Arkansas cultivars was lower ranging between 2-57% (Table 1). Regeneration response was tested by two parameters, greening of callus and the shoot formation. Early callus responders were generally better regenerators, except, Medark, which responded late (5 week) but regenerated highly efficiently (Table 1). While, Arkansas cultivars showed lower efficiency in regenerating shoots in comparison to the model cultivars, healthy shoots were obtained in a number of them (Table 1; Fig. 1b). Most significantly, some of the top cultivars, Roy J, LaKast, and Titan, generated embryogenic callus and regenerated shoots at an efficiency that is scalable within a small laboratory set up (Fig. 1a-b). Next, the transformation response of the selected cultivars was tested by two methods: *Agrobacterium*-mediated transformation and the Biolistics™ method. Roy J, Taggart, and LaGrue were transformed by both methods, although, at a lower efficiency by *Agrobacterium* as compared to Biolistics™, and at 4-8× lower efficiency than the model cultivar, Nipponbare (Table 1). The transformation rate of Arkansas cultivars was 2× higher with Biolistics™ methods, albeit at much lower rate compared to that of Nipponbare (Table 1). Notably, transformed events strongly expressing GFP gene (image not shown), were obtained from 7 cultivars in small-scale experiments consisting of 5 callus plates per experiment (Table 1). Some of these included Roy J, LaKast, Francis, and Taggart.

Significance of Findings

Several rice cultivars developed in the Arkansas rice breeding program generated embryogenic callus that regenerated healthy plants. Some of the best tissue culture responders included Roy J, LaKast, LaGrue, Medark, Titan, and Francis. The tissue cultures of these cultivars were successfully transformed as indicated by stable expression of the GFP gene delivered by *Agrobacterium* or the gene gun. Three cultivars, Roy J, Taggart, and Francis, were found to generate transformed events at >2% efficiency. These observations indicate that the practical approaches of targeted mutagenesis and gene editing can be developed and directly implemented on Arkansas rice cultivars. The implementation of gene editing will expand the resources of genetic variation for the breeding programs.

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Table 1. Tissue culture response of Arkansas rice cultivars.

	Variety	Grain type	Callus response[a] 2 wk	Callus response[a] 4 wk	Regeneration response[b] Greening	Regeneration response[b] Shoots	Transformation response[c] Agrobact.	Transformation response[c] Biolistics
			---------- (%) ----------					
1	Cybonnet	L	38	--	12	0	--	--
2	Wells	L	14	--	0	0	--	--
3	Roy J	L	49	--	81	64	1/plate	2.6/plate
4	Taggart	L	44	--	62	25	2/plate	2.2/plate
5	LaKast	L	56	--	75	62	--	0.5/plate
6	LaGrue	L	32	--	36	36	1/plate	2.0/plate
7	Medark	M	0	28	100	75	0	0.5/plate
8	Spring	L	0	2	0	0	--	--
9	Ahrent	L	14	--	0	0	--	--
9	Titan	M	33	--	25	25	--	0.4/plate
10	Millie	L	8	--	0	0	--	--
11	Banks	L	0	32	0	0	--	--
12	Francis	L	36	--	33	33	--	2.2/plate
13	Newbonnet	L	0	28	50	50	--	--
14	Katy	L	54	--	0	0	--	--
15	Alan	L	32	32	12	0	--	--
16	Templeton	L	0	25	0	0	--	--
17	Diamond	L	0	57	36	18	--	--
18	Keybonnet	L	0	28	50	25	--	--
19	Drew	L	0	28	0	0	--	--
20	Tebonnet	L	0	28	0	0	--	--
22	Nipponbare (model)		100	--	90	80	8/plate	12/plate
23	Kitaake (model)		100	--	100	70	--	--

[a] Percent of mature seeds that generated embryogenic callus after 2 or 4 weeks.
[b] Percent of embryogenic callus that generated green callus and regenerated plants (shoots).
[c] Number of hygromycin-resistant, green fluoresecent clones obtained on a plate subjected to transformation. Each plate contained more or less the same amount of callus.

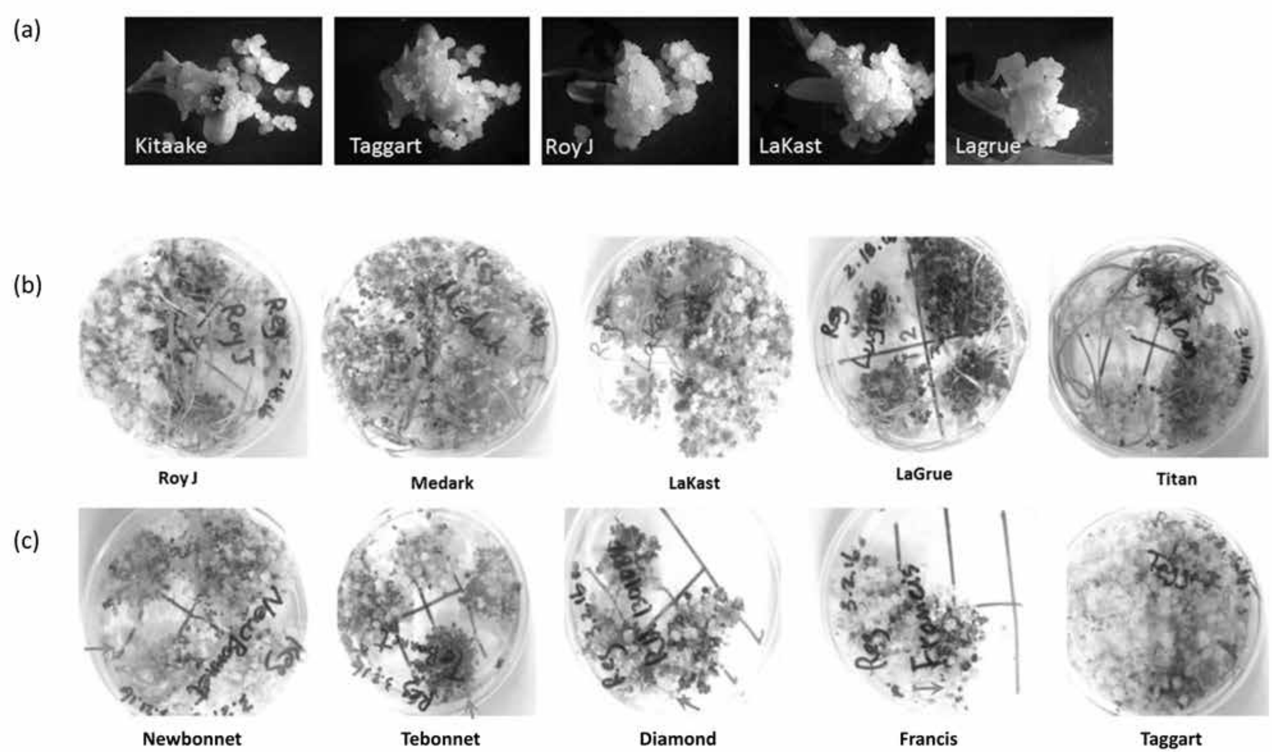

Fig. 1. Tissue culture response of selected Arkansas rice cultivars. (a) Callus obtained from mature seeds within 2 weeks of culture on tissue culture media from the Arkansas cultivars (names indicated) and the model variety, Kitaake. The callus morphologies, indicative of embryogenic callus, were photographed after 2 weeks in culture; (b-c) Regeneration of healthy shoots after 6 weeks in the appropriate regeneration media from the Arkansas rice cultivars. The faster regenerators are shown in (b) and the slower regenerators in (c). Note the elongated shoots in panel (b) as compared to small shoots, indicated by arrows, in panel (c).

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) near 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 mm cwt 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 2017.

Results and Discussion

In 2016, 89 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 2017 at University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC), near Stuttgart, Ark., for observation and selection.

Panicles were selected from 43 F_2 populations in 2016. The parents in these crosses were selected for their aromatic seed quality or high yield potential. Approximately 1450 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 2017. Panicle rows from 65 ranging from F_3, F_4, F_5, F_6, and F_7 populations will be grown in 2017 for observation. Selections from these populations will be harvested and samples from the 65 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 2018.

In 2016, 137 heterozygous lines from 35 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 2016, 18 aromatic lines were evaluated for yield. In the Aromatic Stuttgart Initial Test (ASIT), which has four replications, 18 aromatic lines were evaluated for yield and advanced in the program. In the four-replication Aromatic Advanced Yield Trial (AAYT), 17 aromatic experimental lines were evaluated for yield and and maintained in the program for possible future release. Seed from the top yielding 12 experimental lines with preferred plant types from the ASIT and AAYT were milled and cooked in a taste test during the winter 2017. 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 2017. Five aromatic experimental lines have also been entered in the 2017 Uniform Regional Rice Nursery (URRN).

In 2016, four Jasmine type experimental lines were entered in the Cooperative URRN. The Arkansas mean yields for the four lines were: EXP14105, 139 bu/acre; EXP15102, 106 bu/acre; EXP16105, 160 bu/acre; and EXP15108, 136 bu/acre. The Arkansas URRN two-year average yields were: 157, 129, and 144 bu/acre, respectively, for EXP14105, EXP15102, and EXP15108. The three-year average yield of EXP14105 was 175 bu/acre.

Four experimental lines were also entered in the 2016 ARPT. The mean yields for the four lines were: EXP14105, 162 bu/acre; EXP15102, 147 bu/acre; EXP15108, 155 bu/acre, and STG13-035, 140 bu/acre. The ARPT two-year average yields were: EXP14105, 152 bu/acre; EXP15102, 143 bu/acre; and EXP15108, 145 bu/acre. The ARPT three-year average yields were: EXP14105, 159 bu/acre and EXP15102, 142 bu/acre.

Two experimental lines are being considered for release in 2018, EXP14105 and EXP15102. The line EXP14105 originated from a cross between Jazzman and a plant introduction line. The EXP15102 line originated from a cross between Jazzman and an experimental Drew line. Both aromatic lines have excellent flavor and will continue to be examined in the ARPT and URRN in 2017. Breeder seed of both EXP14105 and EXP15102 will be planted, which will serve as a small foundation seed increase in 2017 as well as seed to plant the 2018 foundation seed field.

Acknowledgments

The authors appreciate the financial support of the rice producers of Arkansas through monies administered by the Arkansas Rice Research and Promotion Board. Support was also provided by the University of Arkansas System Division of Agriculture. We thank Xue Jin for assistance in conducting marker analysis.

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Rice Breeding and Pathology Technical Support

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Abstract

Breeding for disease resistance is one of the objectives of the rice breeders and pathologists at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC) near Stuttgart, Ark. Although breeding and pathology have different programs, the center's plant pathology group has been assisting rice breeders by evaluating preliminary and advanced breeding materials for major rice diseases under greenhouse and field conditions. Most breeding materials are evaluated using artificial inoculation for blast and sheath blight diseases at the RREC and University of Arkansas System Division of Agriculture's Pine Tree Research Station (PTRS) near Colt, Ark. Each year, large amounts of inocula are produced in the laboratory and applied to rice using specific protocols. Evaluation of rice for sheath blight resistance/tolerance is under field conditions while rice blast is screened in both the greenhouse and field environments. Rice breeding programs utilize the obtained data appropriately either to transfer genes for resistance into adapted high yielding varieties or directly to advance the entries for further agronomic testing. The breeding and pathology technical support group is also involved in the University of Arkansas System Division of Agriculture's Cooperative Extension Service rice pathology program. The group assists in the area of applied research on the major prevailing and newly emerging rice diseases, including collaborative interdepartmental, industry, and multi-state research endeavors.

Introduction

Both rice breeders and pathologists work together to develop varieties having desirable disease resistance along with desired agronomic traits. Disease evaluation of rice for major diseases begins in the early generations of plant selection and is a required activity for a successful breeding program. Lines having some potential disease resistance but that lack the agronomic threshold for release may become useful parents for transferring resistance to new varieties.

Rice blast, caused by *Magnaportha grisea* (T.T. Herbert) M.E. Barr, is an ongoing problem so both leaf and neck/panicle blast are included in the screening activities. Rice

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seedlings from the greenhouse are evaluated for resistance to leaf blast while mature plants in the field are screened for resistance to neck/panicle blast. Screening rice for blast disease requires favorable environmental conditions prior to and after inoculation for the pathogen to cause disease.

Sheath blight caused by *Rhizoctonia solani* Kuhn, is another major fungal disease of rice that is often prevalent in rice fields. Evaluation of rice for sheath blight resistance/tolerance is made on fully grown breeding materials in the field at University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC) near Stuttgart, Arkansas. While no qualitative resistance to this pathogen exists, knowledge of whether a variety can tolerate infection through reduced spread of the pathogen is valuable to breeding programs.

Bacterial panicle blight (BPB) caused largely by *Burkholderia glumae* (Kurita and Tabei), formerly known as *Pseudomonas glumae*, has also gained attention in recent years since many of the conventional rice varieties are susceptible to the bacterium. Various research has been ongoing in the laboratory, greenhouse, and field directed at developing practical management options to minimize the impact of this disease on rice yield and quality.

In addition to directly contributing to various research projects, the breeding pathology support group is also involved in training students and support staff in all aspects of the laboratory, greenhouse, and field responsibilities. This allows flexibility in assigning daily activities to accomplish responsibilities in a timely manner for the breeding and extension programs.

Procedures

Evaluation of Breeding Materials for Blast Resistance in the Greenhouse

In 2016, nearly 340 entries from the Uniform Regional Rice Nursery (URRN), Arkansas Rice Performance Trials (ARPT), and advanced lines were planted in flats as triplicate hill plots and evaluated using 5 races of *M. grisea* individually per test. Inoculum production and disease establishment followed earlier described procedures (Kelsey et al., 2016). Disease data were collected between 7 to 10 days after inoculation using both a disease severity rating scale of 0 (healthy tissue) to 9 (elongated necrotic tissue) and an incidence percentage relative to lesion coverage on a scale of 1 (single leaf or lesion) to 100 (all leaves necrotic with multiple lesions). Tests were duplicated for up to 6 independent disease ratings per entry.

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

The blast disease nursery at Pine Tree Research Station (PTRS) near Colt, Ark., was established on 10 June in a secluded area having a tree line border on 3 sides of the test. The fourth side was planted with several rows of corn to serve as a windbreak. The study included 273 entries from the URRN/ARPT collection in 4 replicated hill plots surrounded by a spreader mixture of susceptible lines to encourage spore buildup and disease spread within the nursery. A total of 120 gallons of corn chops/ryegrass was used to produce an inoculum mixture of 5 pathogen races. Over the course of two field visits, rice plants were inoculated using semi-dried seed media beginning at the boot split stage. About 6 weeks after inoculation, plants were rated for head and panicle blast development.

In testing for sheath blight tolerance, two nurseries were planted at the RREC on 26 April in 2 adjacent bays. Each nursery contained an identical set of the 273-hill plot entries used to evaluate field blast with 4 replications per bay. Two 16-gallon batches of air-dried inoculum of corn chops/ryegrass were prepared in the lab to represent "fast"- and "slow"-growing *R. solani* isolates. Each bay received either fast- or slow-growing inoculum to plants at panicle initiation at the rate of 24 g per 6-hill plots. A month later, evaluation of each hill plot for the fungus was made with a rating scale of 0 (no disease) to 9 (severe disease that surpassed the flag leaf). Disease presence of false smut (*Ustilaginoidea virens*) and/or kernel smut (*Tilletia barclayana*) was also noted at the time of scoring for sheath blight using a 0 (no disease) to 5 (severe disease) rating scale.

Assistance to the Cooperative Extension Service Rice Pathology Program

Breeding pathology technical support assisted with the planting of 10 field experiments associated with management studies on sheath blight, early-season seedling disease, blast, and bacterial panicle blight. The group also participated in the evaluation of 20 commercial lines in four replications planted in a farmer's field having a known history of autumn decline/hydrogen sulfide toxicity. Over 35 gallons of CCNT media, a selective media for *B. glumae*, was produced not only to monitor survivorship of the bacterium for six months in soil and seed/crop residues, but also to check approximately 150 panicle samples collected from rice plots in 2016.

Field research, in collaboration with chemical industries included 6 products totaling 24 plots for sheath blight; an early-season seedling disease evaluation with 10 products that totaled 40 plots; and 7 other products that created 28 plots to study efficacy on bacterial panicle blight. Along with these industry studies, additional field research from 72 plots generated data for economics of fungicides on sheath blight and compared fungicide efficacy on sheath blight. Sheath blight inoculum production for sheath blight testing totaled 80 gallons.

Results and Discussion

As part to the breeding program, disease assessment of rice for resistance/tolerance to sheath blight and blast was completed. Field inoculation for sheath blight was modified with use of *Rhizoctonia* isolates classified as "fast" or "slow" as determined by their rate to colonize culture media and plant tissue in the greenhouse. The rationale to include slower colonizing isolates was to address a possible concern that fast-growing isolates alone would overwhelm any amount of resistance/tolerance a cultivar might have to the pathogen. As hypothesized, the data showed doubled recovery of tolerant entries to sheath blight using the slow-growing isolate compared to those using the fast-growing *Rhizoctonia* isolates (Table 1). The fast and slow fungal isolates identified entries with little overlap (up to 2 entries) so there appeared to be a benefit to using isolates from both groups in future disease nurseries.

Entries were also rated for their tolerance to the natural occurrence of smut diseases. Given a natural infection and in the absence of a susceptible check, the disease pressure appeared sufficient to identify the susceptible entries to smut. The smut data also showed at least 50% of the ARPT and URRN entries to be relatively tolerant to false and/or kernel smut when compared to those entries that rated 5 (Table 1). These tolerant entries may also include some entries that escaped infection possibly due to their maturity. Additionally, occurrence of natural smut diseases may not be distributed uniformly across the nursery. Rice smut diseases particularly kernel smut is highly dependent upon favorable wet weather conditions during flowering.

The field blast nursery showed several promising entries from the URRN and ARPT as tolerant to head/panicle blast (Table 1). Although this outcome was encouraging, the checks had lower than expected levels of susceptibility. Above average temperatures of August coincided with inoculation timing and the blast disease did not progress as desired to result in an effective disease epidemic. Nevertheless, some very susceptible entries showed signs of the pathogen and were identified as susceptible.

Of the 333 experimental lines tested for leaf blast in the greenhouse, several were rated as disease tolerant (Table 2). Collection of data for incidence along with the usual severity data was helpful for distinguishing entries with smaller differences in their genetic resistance. Increasing the replications to 6 provided more data that the breeder could use in deciding whether to advance or discard an entry.

Over all, breeding pathology technical support has contributed useful data to support the rice breeding programs along with valuable assistance to the success of research activities in extension pathology starting from preliminary to completed studies of applied research, collaborative research with industries, and interdepartmental research.

Significance of Findings

The goal of the rice breeding and pathology technical support group is to provide information that increases the efficiency of rice breeders in developing maximum yielding cultivars with the desired level of disease resistance. The group also plays a needed role in extension plant pathology by assisting with applied research. A strong applied research approach provides dependable and practical solutions to rice producers in Arkansas and other rice-producing states in the mid-South region of the U.S.

Acknowledgments

The authors gratefully acknowledge the Arkansas rice producers and their support through the monies administered by the Arkansas Rice Research and Promotion Board and the University of Arkansas System Division of Agriculture through their continued interest and funding. Thanks also go the USDA-ARS for their cooperation, interest, and evaluation of materials and to other University of Arkansas System Division of Agriculture Research Stations located throughout Arkansas for their continued support.

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Table 1. Number of entries rated disease tolerant in 2016 field disease nurseries.

Test	Total entries	Sheath blight[a] Fast grow	Slow grow	Fast & slow	Head/ panicle blast[b]	Smut disease[c] False	Kernel
		------------	(0-6 rating)	--------	(0-4 rating)	---- (0-2	rating)---
ARPT	73	5	10	2	39	39	49
URRN	200	7	16	1	109	124	135

[a] Rating scale of 0 (no disease) to 9 (severe disease) was used. A "6" represents disease progression of approximately 60% up the plant.
[b] Five races bulked together for blast field screening.
[c] Rating scale of 0 (no disease) to 5 (severe disease) was used. A "2" represents moderately tolerant entries.

Table 2. Number of entries rated disease tolerant[a] for 2016 greenhouse leaf-blast testing.

Test	Total entries	IE-1K	IC-17	IG-1	IB-49	IH-1
ARPT	73	21	33	42	16	57
URRN	200	68	112	153	40	160
Advance lines	60	30	32	44	17	43

[a] Disease severity rating scale of 0 (no disease) to 4 (small diamond shaped lesion with ashy center).

Studies on Variables Related to the Survival and Severity of *Burkholderia glumae*, the Major Pathogen for Bacterial Panicle Blight of Rice in Arkansas

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Abstract

Bacterial panicle blight (BPB) is one of the most threatening diseases for rice production in Arkansas and other southern rice-producing states. The disease is mainly caused by *Burkholderia glumae* and possibly other *Burkholderia* species. As part of short-term strategies to manage BPB, two objectives were addressed in this study, 1) to evaluate survival of *B. glumae* in infected rice residues and inoculated soil, and 2) to evaluate the effect of dew associated with severity and incidence of BPB in the greenhouse and in shaded areas of the field along tree lines. Despite the high initial population density in artificially inoculated soils, *B. glumae* appeared to be short lived. In 2015, no colonies of *B. glumae* were recovered from soil that had been inoculated a month earlier and left on the surface of the field or buried. In 2016, at 2 weeks after inoculation, *B. glumae* was recovered but at a much lower population density. Based on these results, *B. glumae* appears less likely to over-season and infect new rice plants from soil. When tested using infected panicles placed on the surface of field soil or buried in the field, none of the florets tested positive for BPB from the panicles placed on the surface or buried after a month in 2015. In 2016, again no positive kernel/chaff were obtained from the panicles on the surface. However in the buried panicles, a 2% recovery continued for 3 months suggesting low survivorship of *B. glumae* in panicles that overwinter under field conditions. When artificially inoculated rice plants were left as volunteer to over-winter, the number of positive seeds dropped from 25% to 10% in 1 month and to 0 during the remaining 5 sampling months. Results from the "volunteer" plants of 2016 were in agreement with the buried residue treatment that showed a higher survivorship of the *B. glumae* in kernel residues than in the soil alone. The greenhouse dew test and the tree line shade test agreed on higher incidence of BPB disease. The east side shade was more conducive than the west side rendering twice the number of infected panicles and nearly four times higher than the no shade treatment suggesting the positive role of extended morning dew periods in the field in favoring BPB disease development.

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Introduction

Bacterial panicle blight (BPB) disease of rice is caused by *Burkholderia glumae*, *B. gladioli*, and possibly a few other species of *Burkholderia*. Bacterial panicle blight is often associated with extended hot and dry daytime weather and warm nighttime temperatures. Under favorable environmental conditions for pathogen development and spread, up to a 60% yield loss can occur in susceptible rice cultivars. Panicle symptoms typically develop late in the season during grain fill which makes it difficult to visually predict disease occurrence and severity to minimize damage. Infected panicles have two-tone discoloration where the blighted florets appear white to light gray with a dark-brown margin on basal third of the tissue. As the season tapers, infected florets turn straw-colored and with time may further darken with growth of other opportunistic microorganisms. Heavily infected panicles remain upright due to lack of grain fill. Weather variables of temperature, moisture, and wind are observed to play an important role in BPB disease incidence and severity. Although the life cycles of the panicle blight-causing bacteria are not completely understood, they have been found in residue, soil and water. However, longevity and infectivity from these sources have not been well studied. The objectives in this study are 1) to evaluate survival of *B. glumae* from infected rice residues and inoculated soil; and 2) to evaluate the effect of dew associated with severity and incidence of BPB in the greenhouse and in shaded areas of the field along tree lines.

Procedures

Research on the Survival of *B. glumae* in Soil

Three batches of approximately 4.5 lb of silty loam soil were air-dried and pulverized to obtain a homogenous mixture of soil. A 48 h culture of *B. glumae* on Kings B agar medium was washed to prepare 600 mL of a bacterial suspension with optical density (O.D.) transmittance of 9 and 78. Each O.D. suspension was added separately to a batch of soil and thoroughly mixed. A subsample representing each O.D. was removed to quantify the initial population of *B. glumae* present at the beginning of the experiment. The remaining soil for each O.D. was divided into 200-g samples and shaped to form 10 columns that were individually wrapped with nylon mesh and used as treatments on "surface" and "buried at 6-inch depth". A negative control was also prepared using sterile water. For the next 5 months, a column of soil for each of 3 treatments was removed from the field and brought to the laboratory to determine the *B. glumae* population. Enumeration of bacteria from soil was performed using 1 g soil per 10 mL sterile water in a culture tube. The soil suspension was vortexed for 5 sec prior to removal of a 1 mL aliquot to create a series of 1:10 dilutions. For each dilution, 100 µl was plated onto each of 2 CCNT plates. The CCNT contained 2 g of yeast extract, 1 g of polypepton, 4 g of inositol, 10 mg of cetrimide, 10 mg of chloramphenicol, 1 mg of novobiocin, 100 mg of chlorotharonil and 18 g of agar in 1000 mL of distilled water, and was adjusted to pH 4.8 (Kawaradani et al., 2000). Plates were incubated at 38 °C to 40 °C (100 °F to 104 °F) for 48 h before they were checked for colonies producing a distinct yellow pigment in the CCNT agar medium. Colony forming units (CFU)/mL were determined only for plates with distinct yellow forming colonies.

Research on the Survival of *B. glumae* in Rice Residue

Rice panicles previously inoculated with *B. glumae* and observed with classic symptoms of bacterial panicle blight were selected to create 10 bundles each with 5 panicles. Twenty seeds were randomly selected across each panicle to obtain 100 seeds per bundle. Seeds were embedded into CCNT media and placed in an incubator at 38 °C to 40 °C for 48 h. The number of seeds with a transparent yellow pigment were counted as positive. Each bundle of panicles was carefully wrapped in nylon mesh and tagged for use in "surface" and "6-inch buried" residue treatments. For the next 5 months, a bundle of panicles for each of 2 treatments was removed from the field and brought to the laboratory to determine the number of seed positive for *B. glumae*.

Off-Season Field Survival of *B. glumae* in Inoculated Rice

B. glumae-inoculated rice plants that showed a high level of BPB disease in the Uniform Regional Rice Nursery (URRN)/Arkansas Rice Performance Trial (ARPT) bay were tagged to remain out in the field after harvest. Starting in October, 5 panicles were randomly picked every month. From each panicle, 5 seeds were randomly removed and plated on CCNT media. In the absence of whole seeds with endosperm, glumes/chaff were plated. The number seeds/chaff that tested positive were recorded. The test was carried out in 2015 and 2016.

Effect of Dew on Severity/Incidence of Bacterial Panicle Blight

Dew Chamber Versus Greenhouse Bench Study: Four varieties namely, Caffey, CL151, Jazzman 2, and CL172 were grown in 2-gallon buckets until flowering in the greenhouse at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC) near Stuttgart, Ark. The first 3 panicles to flower in a pot were inoculated with a *B. glumae* suspension of approximately 10^8 CFUs. One pot of each cultivar was kept in a dew chamber at a temperature of 78 °F and humidity near 100% for 24 h after inoculation. The replicate pots were placed on a greenhouse bench. The plants in the dew chamber were removed after 24 h and also kept on the bench. Plants were regularly checked for BPB symptom development until symptomatic kernel counts were made.

East and West Side Tree Line Effect on Incidence of Bacterial Panicle Blight: A horseshoe-shaped field surrounded by trees was selected at the University of Arkansas System Division of Agriculture's Pine Tree Research Station (PTRS) near Colt, Ark. Bengal seeds were planted in 3 separate bays spaced across the field: one close to the eastern tree line, the second near the western tree line, and the third at the center of the field that received no tree shade. Artificially inoculated and non-inoculated seeds were planted each in 4 plots (5 ft by 15 ft) for each bay. All 3 bays were maintained and treated similarly. The number of panicles with BPB symptoms was recorded at early grain fill. Panicle counts were analyzed using SAS v. 9.3 (SAS Institute, Inc., Cary, N.C.).

Results and Discussion

Research on the Survival of *B. glumae* in Soil

Regardless of the high initial CFU/g in the infested soils, *B. glumae* appeared to be short lived in soil. In 2015, no colonies of *B. glumae* were recovered from the soil when tested a month after the infested soils were left on the surface of field soil or buried. In 2016, at 2 weeks after inoculation it was possible to detect declined CFU numbers of *B. glumae*. However in subsequent tests, there was no recovery of the bacterium. The control non infested soil showed other soilborne bacteria but not *B. glumae* (Table 1). Based on these results, *B. glumae* seemed less likely to over-season and infect new rice plants. Survey results in 2015 and 2016 from BPB sample collection showed *B. glumae* as the major causal of BPB disease in Arkansas.

Research on the Survival of *B. glumae* in Rice Residue

Positive florets/kernels for BPB in the initial samples ranged from 26% to 32% in 2015 and 17% to 29% in 2016. None of the florets tested positive for BPB from the panicles placed on the surface or buried after a month in 2015. In 2016, no kernel/ chaff was obtained from the panicles on the soil surface. However with buried panicles, a 2% positive recovery continued for 3 months (Table 2). The 6 month test was negative for all of the panicles left on the surface or buried.

Off-Season Survival of *B. glumae* in Inoculated Rice

In 2015, rice plants artificially inoculated with *B. glumae* left to overwinter dropped from 25% to 10% positives in one month and to 0 during the remaining sampling months. Similarly, inoculated plant materials left in the field during the fall and winter season of 2016 showed a gradual drop in *B. glumae* survival to 0% by the fifth month of sampling from the initial sample of 26% (Table 3). Results from the overwintered plants of 2016 are in agreement with the buried treatment residue test of 2016, showing a higher probability of *B. glumae* survivorship in plant residues, particularly kernel residues than in soils. However, there was no indication of survivorship for 6 months.

Effect of Dew on Severity/Incidence of Bacterial Panicle Blight

Dew Chamber Versus Greenhouse Bench Study: An experiment utilizing the dew chamber determined that dew affected BPB incidence resulting in floret infection differences that ranged from 34% to 68% in four rice cultivars Caffey, CL151, Jazzman 2, and CL172. These percentages of infection under the dew only required a 24-h dew exposure following artificial inoculation at the rice flowering stage. The results clearly showed more symptomatic florets with a dew environment compared to florets that were left on the bench (Fig. 1). While BPB is favored by hot and dry conditions, disease symptoms are more pronounced when moisture i.e. dew, mist, rain or windy rain is present. Field observations are in agreement with these findings.

Comparison of East and West Side Tree Line Effect on Incidence of BPB: Three bays planted with inoculated and non-inoculated Bengal seeds showed no significant differences due to inoculations. There were no significant differences among replications or for the interactions between inoculation and location. However, the locations related to length of shade (east side, west side, and no shade) showed significant differences in infected panicle count (Fig. 2). The east side plots with longer shade periods for the morning dew had nearly twice the infected panicles as the west side shaded plots with a shorter dew time, and nearly four times more infected panicles than the unshaded plots. These findings agree with the observation in 2012 where Jazzman 2 in Lee County had severe BPB near trees and bayou areas and greatly reduced BPB in areas away from the tree line. The experiment will be repeated in the same location in 2017.

Significance of Findings

Managing bacterial panicle blight of rice is very important to reduce the potential yield losses. With lack of resistance in current commercial rice cultivars and absence of chemical options, understanding the biology of the pathogen is important for the discovery of effective management strategies for the disease. Cultural management options can always be integrated with host resistance. These studies and findings are important from both scientific and practical points of view. Rice plants are most susceptible at the flowering growth stage and any form of moisture under hot weather at this stage can make rice prone to BPB disease. Knowledge of the short-term survival of *B. glumae* in soil and residue is pertinent to the knowledge of inoculum sources.

Acknowledgments

Special appreciation is extended to the Arkansas producers for their funding which is administered by the Arkansas Rice Research and Extension Board; the University of Arkansas System Division of Agriculture for providing funding and support; Rick Cartwright for his technical advice; and Jarrod Hardke for his positive feedback.

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Table 1. Survival of colony forming units (CFU) of *B. glumae* found in soil inoculated with two density levels of bacterial suspension on soil surface and buried at a 6-inch depth for 6 months (Oct-March) in 2015-2016 and 2016-2017.

		O.D.[a]	Initial CFU/g of soil	2 wk[b]	Nov-March
2015 Soil	Surface	9	6.9×10^9	NA	0
		78	5.3×10^8	NA	0
		Control	0	NA	0
	Buried	9	6.9×10^9	NA	0
		78	5.3×10^8	NA	0
		Control	0	NA	0
2016 Soil	Surface	9	3.6×10^6	2×10^5	0
		78	1.7×10^6	7×10^3	0
		Control	0	0	0
	Buried	9	3.6×10^6	0	0
		78	1.7×10^6	0	0
		Control	0	0	0

[a] O.D. = optical density.
[b] The 2-week test was added in 2016 since no *B. glumae* was detected in 2015 after one month. The differences in initial *B. glumae* population recovered could be due to the differences in soil sources in the respective years.

Table 2. Percentage of seed with a positive initial infection of *B. glumae* compared to the percentage of positive seeds recovered after surface and buried treatments for the 6-month period.

			2 wk	Nov	Dec	Jan	Feb	Mar
2015 Panicle	Surface	% Initial positives	NA[a]	28	26	26	32	30
		% positives across time		0	0	0	0	0
	Buried	% Initial positives	NA	35	27	31	33	24
		% positives across time		0	0	0	0	0
2016 Panicle	Surface	Initial positives%	20	19	16	19	18	20
		% positives across time	0	0	0	0	0	0
	Buried	Initial positives %	24	26	20	26	29	17
		% positives across time	0	2	2	0	0	0

[a] NA = not available because not included in the test in 2015.

Table 3. Percentages of initial seeds infected and recovered as positive for *B. glumae* from inoculated rice as compared to positive seeds/chaff recovered in subsequent sampling timings for the 6-month period.

	Seeds positive for *B. glumae* (%)						
Year	Oct	2 wk	Nov	Dec	Jan	Feb	Mar
2015	25	NA	10	0	0	0	0
2016	26	12	11	5	2	0	0

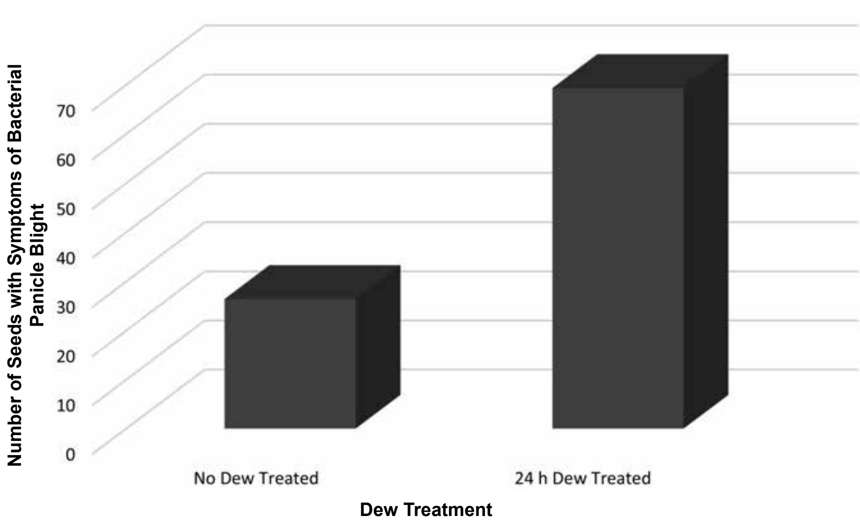

Fig. 1. Mean number of seeds that showed bacterial panicle blight (BPB) symptoms when treated with dew and no dew treatment in the greenhouse at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center, near Stuttgart, 2016.

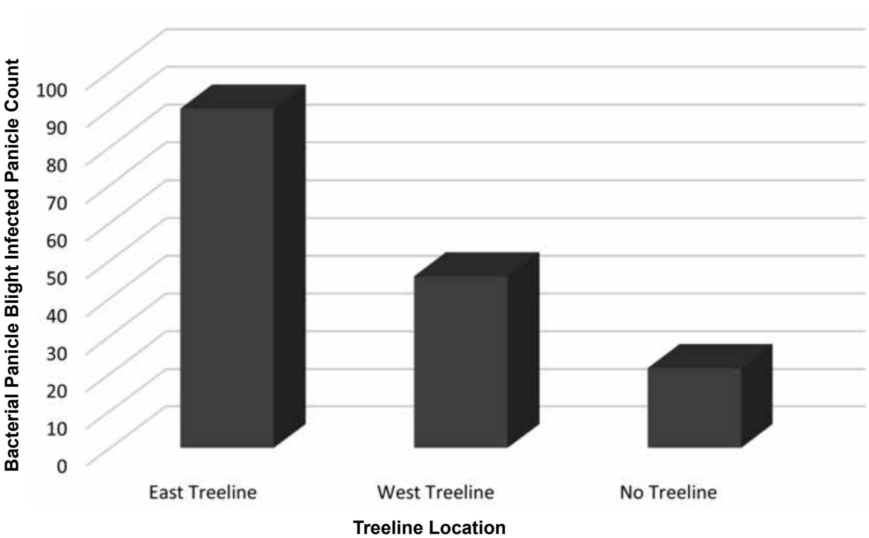

Fig. 2. Mean bacterial panicle blight infected panicle count per plot at the University of Arkansas System Division of Agriculture's Pine Tree Research Station near Colt, 2016.

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

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

Abstract

Bacterial panicle blight (BPB), caused mainly by the bacterial pathogen *Burkholderia glumae* has posed a higher level of threat to rice production worldwide in recent years. Here, we report the response of over 300 entries evaluated by artificially inoculating plants with a bacterial suspension under field conditions. From the field screening, about 24% and 11% of the entries showed resistant and moderately resistant reaction, respectively. Moreover from symptomatic samples collected, nearly 85% of the samples were positive for *B. glumae*. At no time was *B. gladioli*, the second reported causal bacterium for BPB disease in rice, recovered from any of the samples. Greenhouse tests with slow-growing isolates of *B. glumae* resulted in two isolates (RREC-46 and RREC-114) that can potentially be used to screen rice genotypes at the seedling stage. These two isolates showed more consistency in lesion length when inoculated on seedlings of eight rice cultivars of known susceptibility. The lesions on known susceptible cultivars such as Jazzman 2 and CL151 were longer than lesions on more resistant varieties such as Jupiter and hybrid rice.

Introduction

Bacterial panicle blight (BPB) is a relatively new disease in the U.S. and is threatening rice production in southern rice states. Bacterial panicle blight disease of rice is mainly caused by the gram-negative bacteria, *Burkholderia glumae* and *B. gladioli*. Although several other disorders can result in rice panicle sterility, the symptoms associated with BPB are usually evident if detected early as grain filling starts. The brown discoloration associated with BPB on the bottom of developing florets changes as saprophytes grow on the sterile or dead floret tissues making the symptoms confusing at later stages of the rice plant's development. Overall, symptoms include panicle discoloration, grain rot, and aborted or sterile florets. Panicles remain upright in the field because of BPB blanking. Bacterial panicle blight is favored by prolonged high night-temperatures during the heading and flowering stages of the crop (Nandakumar

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et al., 2009). To date, severe BPB incidences have not been reported on hybrid rice in Arkansas. In 2016, some rice fields were affected by BPB to various degrees. Chemical options are not yet available to manage BPB. This report surveys pathogen populations related to BPB as part of the search for long-term management in developing resistance sources and tools.

Procedures

Evaluation of Rice for Resistance Against Bacterial Panicle Blight Disease

In 2016, entries in the Arkansas Rice Performance Trials (ARPT) and the Uniform Regional Rice Nursery (URRN), 75 and 200 entries, respectively, were evaluated for BPB disease of rice at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC) near Stuttgart, Ark. Two sets of 275 entries were planted as "early" on 24 April and "late" on 18 May along with their respective control sets. Entries were planted as duplicate hill plots interspaced with Jupiter and Bengal after each 10 test entries. Jupiter and Bengal were included as references for moderately resistant and susceptible cultivars, respectively. Entries were spray-inoculated using *B. glumae* bacterial suspension following the procedure in Wamishe et al. (2012). Disease reactions were evaluated three weeks after the last inoculation using a 0 to 5 scale, where 0 is no disease and 5 is severe disease (Table 1). In addition to the 2016 URRN and ARPT entries, a select group of 59 lines that showed resistant (R) and moderately resistant (MR) reactions to BPB from 2012 to 2015 URRN and ARPT entries, were also planted to further verify their steadiness against BPB.

Isolation and Identification of *Burkholderia Species* from Arkansas Rice

Nearly 129 rice panicle samples that either showed some level of blanking or brown floret discoloration similar to BPB symptoms were collected during field evaluation. Collected panicle samples were kept in brown paper bags to dry at room temperature until processed on culture. About 100 seeds from each sample were randomly picked and plated on CCNT, a semi-selective medium for *B. glumae* (Kawaradani et al., 2000). Ten seeds were placed per plate. Plates then were incubated at 39 °C under dark. Seeds with a typical morphological symptom were counted and bacterial colonies transferred to King's B medium for purification. Pure cultures were kept at -80 °C for further DNA extraction and molecular identification. The molecular identification included a known *B. glumae* isolate from RREC collection as positive control and specific primer pairs for *B. glumae* and *B. gladioli* (Yukiko et al., 2006).

Methods of Screening Host Resistance to Bacterial Panicle Blight in the Greenhouse

Fast- and slow-growing isolates were selected from the *B. glumae* collection at RREC based on an earlier hypersensitivity reaction on wild tobacco. Based on lesion size development on tobacco leaves, isolates were categorized into three virulence levels: low (RREC- 46, RREC-114); medium (RREC-5, RREC-14, RREC-20); and high (RREC-6, RREC-7, RREC-155). Notes from previous field trials helped select nine rice cultivars with different responses to BPB namely, susceptible (Bengal, Jazmann-2, CL151) and moderately resistant to moderately susceptible (Jupiter, RT-XL753, Titan, Mermentau, Caffey, CL172). Each of the rice cultivars were tested with *B. glumae* isolates from the different virulence levels.

A suspension of approximately 10^8 colony forming units (CFU) was prepared for each isolate and handled separately. Rice seedlings at 4 weeks were needle inoculated in the stem using a 1-mL syringe to deliver 0.01 mL of the suspension. After inoculation, rice seedlings were placed on a greenhouse bench and watered and fertilized as needed. Data on lesion length was obtained 4 weeks after inoculation starting from the site of the injection. Lesion length in proportion to plant height was multiplied by 100 to obtain percent lesion size.

Results and Discussion

Evaluation of Rice for Resistance Against Bacterial Panicle Blight Disease

With the absence of chemicals to control BPB, development and use of improved disease resistant rice varieties remains the most important disease management strategy. Some moderately resistant entries in the early planting became moderately susceptible or susceptible in the late-planted set. Nine entries from URRN and 6 entries from ARPT showed resistant reaction in both planted sets (Table 2). The early-planted field evaluation to BPB showed 24% resistant (R) and 36% moderately resistant (MR) rice entries. For the late-planted set, only 11% of the entries were R and 6% MR (Fig. 1). These results agree with earlier reported results where a late planting appeared to favor more BPB disease (Wamishe et al., 2015). Later maturing rice often escaped BPB disease due to the variety's late flowering at the time of inoculation which resulted in no or slight BPB disease. When flowering occurred later in the year, unfavorable weather conditions for BPB disease development prevailed resulting in false negatives (susceptible cultivars with no disease). To mediate a possible escape, repeated tests are required to ensure true BPB resistance in later maturing rice. For example, Roy J has been relatively free of BPB for the past two years but is known to be susceptible. This variety is late maturing so delayed planting defers flowering to a later part of the season when temperatures cool down resulting in a possible disease escape.

Isolation and Identification of *Burkholderia* Species in Arkansas Rice

Of the 129 samples collected from rice fields in 2016, all were positive to BPB based on CCNT culture medium. The percentage of seeds that tested positive for BPB varied from 2% to 74%. Nineteen percent of the samples had less than 10% seeds infected, 53% had 10% to 25% infected seeds, 27% had 26% to 50% and one entry had 74% seeds positive to BPB (Table 3). Some of the samples with severe blanking had a lower percentage of infected seeds. Bacteria isolated from seeds with CCNT and resembling *B. glumae* were purified. DNA was extracted and identified using molecular techniques. Among the isolates, nearly 85% were positive for *B. glumae* while the remaining 15% indicated bacterial species different from *B. glumae* or *B. gladioli*. Although culture-based identification has been useful as a first-step process, the fact that not all translucent yellowing forming colonies on CCNT were *B. glumae* indicated the need for a molecular approach to confirm the bacterium. Survey results of 2016 agree with the previous year. From 165 samples collected in 2015, none were identified as *B. gladioli* indicating *B. glumae* as the predominant cause for BPB in Arkansas (Wamishe et al., 2015).

Development of Methods to Screening Host Resistance to Bacterial Panicle Blight in the Greenhouse

To detect resistance-response differences between rice cultivars at the seedling stage in a greenhouse, isolates having differences in growth on culture and hypersensitivity on wild tobacco were selected. Accordingly, two isolates were grouped as isolates with low virulence, three as medium, and three as high (Table 4). Isolates RREC-46 and RREC-114 were selected as isolates with low virulence and when tested on eight rice cultivars rendered lesion sizes with varying lengths. The remaining isolates showed no lesion discrimination between susceptible and resistant varieties. Water-inoculated control rice caused no symptom. Other than variation in lesion sizes, RREC-46 and RREC-114 took longer to show lesions compared to the medium or fast hypersensitive reaction isolates. The test using RREC-46 and RREC-114 isolates will continue further to evaluate more rice genotypes to verify the constancy of resistance.

Significance of Findings

Development of a working toolbox to evaluate genetic resistance remains an important priority toward combating BPB disease in rice. Rice resistance to BPB would provide long-term control especially in years of increased disease pressure. The continuous surveys for *Burkholderia* species across Arkansas provide information useful for research. Efforts in understanding virulence, pathogenicity, and epidemiology of the *Burkholderia* pathogens on rice should be helpful to identify effective BPB disease management strategies.

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Table 1. Disease rating scale and corresponding reaction groups used to evaluate the resistance of rice cultivars to bacterial panicle blight under field conditions sprayed with suspension of *Burkholderia glumae* between late-boot to flowering stage of rice development.

0-5 scale	Reaction group	0-5 scale	Reaction group
0	Immune	3	Moderately susceptible
1	Resistant (R)	4	Susceptible
2	Moderately resistant (MR	5	Very susceptible

Table 2. Resistant and moderately resistant rice entries to bacterial panicle blight for two plantings that were spray-inoculated in the field.

Source	Cultivar	Level of infection	
		Early planted	Late planted
		-----------(0-5 scale) ----------	
URRN	RU1401105	1	1
URRN	RU1503003	1	2
URRN	RU1003123	1	2
URRN	RU1404156	1	2
URRN	RU1601070	1	2
URRN	RU1602115	1	2
URRN	RU1603116	1	2
URRN	RU1603126	1	2
URRN	RU1603153	1	2
ARPT	RT XL760	0	1
ARPT	RT XL753	1	1
ARPT	RU1601070	1	2
ARPT	RU1501176	1	1
ARPT	RU1401105	1	1
ARPT	STG14IMI-06-195	2	2

Table 3. The percentage of kernels that tested positive for bacterial panicle blight from panicle samples collected from different rice cultivars in 2016.

% Kernels positive to BPB	# of Entries	% Kernels positive to BPB	# of Entries
2	5	22	8
4	8	26	6
6	6	28	3
8	5	30	7
10	12	32	5
12	8	34	4
14	9	36	2
16	4	38	2
18	15	40	4
20	7	48	2
24	4	74	1

Table 4. Lesion size for hypersensitivity reaction test of bacterial panicle blight causing bacteria isolates on a tobacco seedling plant.

Isolate no.	Lesion size	Scale	Remarks
	(cm)		
RREC-5	0.9	Medium	
RREC-6	1.6	High	
RREC-7	2.0	High	
RREC-14	1.1	Medium	
RREC-20	1.2	Medium	
RREC-46	0.4	Low	
RREC-114	0.3	Low	
RREC-155	3.5	Very high	Covers the whole leaf area

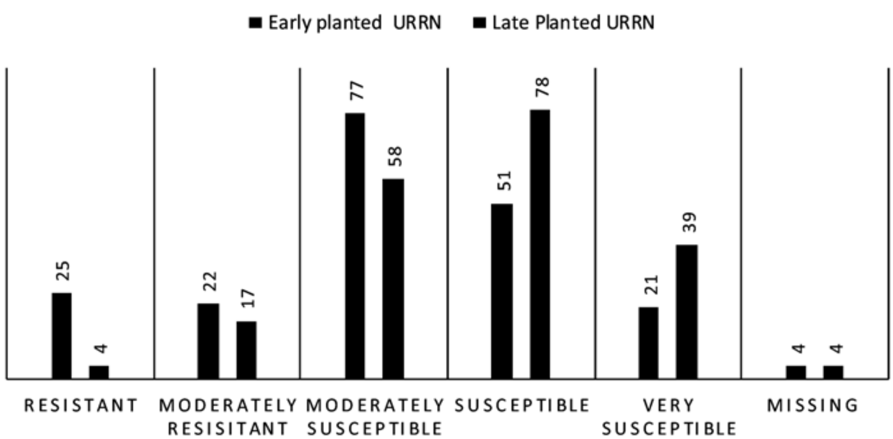

Fig. 1. Number of rice entries in the 2016 Uniform Regional Rice Nursery different reaction category for bacterial panicle blight disease in early-planted (24 April 2016) and late-planted (18 May 2016) and spray-inoculated artificially.

Identifying Management Strategies to Reduce Autumn Decline in Rice

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Abstract

Symptoms of hydrogen sulfide toxicity or autumn decline, also referred to as akiochi, include black root rotting with stunted and yellowish rice foliage starting as early as two weeks following establishment of the permanent flood. In severe conditions, root crowns rot and they are invaded by opportunistic fungi rendering dark brown discoloration and problems in upward nutrient translocation from roots. Greenhouse pot experiments were carried out using two sources of field soil that had frequently shown symptoms. After three tests in the greenhouse using the bio products, oxidizing and other seed dressing compounds, the bio product was selected for field test in micro-plots. The bio product results showed a clean crown without improving the root blackening. In a cultivar response test, using 20 rice cultivars, root blackening ranged from 43% to 60% with none having clean roots. Crown discoloration and rotting ranged between 0% to 57%. Eight of the 20 cultivars showed crown discoloration in more than 10% of the sampled plants, 6 cultivars from 5% to 10% and the remaining 6 from 0% to 3%. Cultivars CLX1024, LaKast, RT 7311 CL, and RTXL753 did not show crown discoloration. The cultivar response rating matrix developed in 2015 appeared well validated with the data obtained in 2016. In the evaluation of the effect of soil drainage on new root growth in the greenhouse, the amount of new root growth continued for 4 days at all growth stages. After the fourth day, rice plants were drought stressed and wilted.

Introduction

Hydrogen sulfide toxicity or autumn decline, also referred to as akiochi, describes the problems seen in some rice fields. Autumn decline often appears in rice fields af-

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fected by hydrogen sulfide in anaerobic/flooded conditions. Symptoms include black roots believed to be caused by iron sulfide and root rotting which results from hydrogen sulfide toxicity. The affected rice plants are stunted with yellowish foliage showing up as early as two weeks following the establishment of a permanent flood. The problem is often most severe where cold well water first enters a rice field and may later spread throughout the field, except on levees. Rice growing on the levees remains unaffected. The phenomenon was reported in Arkansas in a limited number of fields in 2004 (Bennett, 2004; Wilson and Cartwright, pers. comm.). However, several more reports of autumn decline occurred across Arkansas from 2012 to 2016. Although the problem may be aggravated in the anaerobic/flooded conditions, there is no clear understanding of why this phenomenon is occurring with 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 other soil textures commonly cropped to rice. The root rotting symptoms often start a few weeks after flood establishment and become progressively worse throughout the season. In situations where root rotting is severe, fungi grow into the crown which limits the function of the whole root system and prevents translocation of water and nutrients from the soil to the plant resulting in crop decline. 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 started in 2015 have the following objectives: 1) to search for practical methods to prevent or correct the root blackening and rotting associated with autumn decline; 2) to evaluate the degree of resistance or tolerance of common rice cultivars to autumn decline under greenhouse and field conditions; and 3) to evaluate the effect of soil drainage (the current preventative/rescue strategy) on autumn decline severity and cultivar survival rate.

Procedures

Studies on New Strategies to Reduce Autumn Decline

Greenhouse Tests to Evaluate Products in 2015: In the winter of 2015, soil from Hillemann, Ark., in Woodruff County was collected at the beginning of October, approximately a month after rice from the field was harvested. The soil visually appeared light in color with noticeable iron content. A second soil sample was collected from Hunter in the same County. Soil from the Hunter area appeared darker in color and was also collected at the end of October 2015, nearly a month after the soybean harvest. Both soils had big plant residue materials removed by sieving prior to initiating greenhouse tests. A susceptible rice cultivar Mermentau was selected based on its field response in 2015 and planted in 2-gal pots. Flooding in the first set of experiments was maintained with refrigerated water (4 °C) until flowering at which time data was collected. In the second set of experiments, pots were flooded for three weeks before planting to enhance anaerobic situation. Another susceptible cultivar, CL151, was planted in muddy soil and kept wet continuously until permanent flood was established. All pots were fertilized with a general-purpose fertilizer for nitrogen, phosphorus, and potassium (NPK). Treatments included: 1) bio product (old formulation), a product claimed to have sulfur-philic anoxygenic phototrophic bacteria; 2) oxidizing compounds, namely KNO_3, H_20_2 and $KMNO_4$; and 3) a control treatment with a continuous flood. All treatments were replicated twice. Treatment rates added to 2-gal pots were as follows: bio product 10 µl; hydrogen peroxide (H_2O_2) 35% 30 mL; potassium nitrate (KNO_3 fertilizer formulation) 30 g and potassium permanganate ($KMNO_4$) 10 g.

Greenhouse Tests to Evaluate Products in 2016: A different set of greenhouse experiments was conducted in the fall of 2016. Soil was collected from a producer's field in Hunter after the rice harvest. All organic residue in the soil was maintained rather than removed with a sieve. Two sets of pots for 8 treatments were prepared in two replications. One set was pre-flooded for two weeks to enhance anaerobic conditions before planting. The other set used the field soil directly and received no pre-flood conditioning. In each 2-gal pot, nearly 18 seeds were planted. After emergence, weaker seedlings were pulled out to bring the number down to 10 to 12 per pot. Treatments included: 1) bio product, new formulation; 2) CaO_2 seed treatment; 3) CaO_2 flood treatment; 4) CaO_2 plus ZnO seed treatment; 5) CaO_2 plus ZnO flood treatment; 6) ZnO seed treatment; 7) ZnO flood treatment; and 8) the untreated control. Rates for standalone or combination treatments included: 10 µl/pot for bio product; 35 g/100 g seed for CaO_2 and 7 µl/100 g for ZnO. For the flood treatment CaO_2 was applied at 0.1 g/pot and ZnO at 1 µl/pot rate. The flood in pots was maintained with non-refrigerated water until after flowering, and fertilized as needed with liquid NPK. The flood and fertilization in the control pots were maintained similarly. During evaluation, rice plants were carefully pulled out of the pots so the roots could be washed and data recorded.

Field Tests to Evaluate Products in 2016: Among the three oxidizing agents (H_2O_2, KNO_3, $KMNO_4$) and the bio product (anoxygenic phototrophic bacteria) tested in the 2015 greenhouse, the old and new formulations of the bio product showed the best response and were tested in micro-plots under field conditions at Hunter and Hillemann, Ark. A half barrel with 2 ft diameter and 1 ft high was fixed into the soil to a depth of 4 in. The barrels were fixed into the soil a few days before the producers applied preflood nitrogen. The Hunter field was planted with RTXL753 and the Hilleman field with Roy J. At each location, 9 barrels were used for 3 treatments in 3 replications. The treatments included: the old bio product, the new bio product and untreated control. Each replication of 3 treatment barrels was placed in a different bay. Seedling population contained in the barrel varied on the variety and emergence. Treatments were applied 2 weeks after flooding and flood depth was maintained at least to a 4-in. depth until data were collected after flowering stage.

Evaluation of Cultivars for Resistance in 2016

To evaluate rice for degree of resistance or tolerance to autumn decline under field conditions, a field trial consisting of 20 commercial cultivars was planted in 4 replications in 2016 in a field with history near Hilleman, Ark. (Tables 1 and 2). Five cultivars from 2015 were replaced by newer cultivars in 2016. Each plot had 9 rows with 7-in. spacing and a 15-ft length. Data were collected after the early-maturing cultivar flowered and after all cultivars headed. Hand harvested plants were pulled from the left outer row of each plot and thoroughly washed to expose the root system. These roots were rated instantly for root blackening with a 0 to 5 scale and on a crown browning/rotting scale of 0 to 9 as described in the disease matrix developed in 2015 (Table 2). Wherever crown rotting and discoloration varied within a sample, the highest score was taken as potential maximum to summarize the data.

Greenhouse Evaluation of Effect of Soil Drainage on New Root Growth

To evaluate the effect of soil drainage on new root growth, twelve 2-gal pots were filled with soil having a history of autumn decline brought from Hunter Ark. Pots were planted with CL151 and flooded a day after the first nitrogen application or 6 weeks after planting. Flood depth increased as the plants grew taller making a final depth of at least 4 in. A set of 3 pots was drained in two week intervals after the fourth week of flooding i.e, 4, 6, and 8 weeks after flooding.

Results and Discussion

Studies on New Strategies to Reduce Autumn Decline

Greenhouse Tests to Evaluate Products in 2015: In the greenhouse test of 2015, only 27 %, 25%, and 27% of sampled plants showed crown symptoms with the old bio product, H_2O_2, and KNO, respectively (Table1). The continuous flood control showed 100% of plants with crown infection and $KMNO_4$ showed 44% of the sampled plants in soil from Hillemann. In the second set of experiments where soil from Hunter field was used, the bio product showed relatively healthy looking roots compared to the untreated control. A 30 g/pot rate of KNO_3 killed all the plants so no information was obtained. Rice plants treated with H_2O_2 became stunted but roots looked clean. Roots of rice plants treated with $KMNO_4$ were even darker than the control. The performance of the bio product appeared to vary with soil types. With the soil collected from Hunter, rice roots looked cleaner than rice grown in Hillemann soil. The $KMNO_4$ treatment showed more blackened roots when grown in soil from Hillemann than soil from Hunter.

Greenhouse Tests to Evaluate Products in 2016: In 2016, greenhouse tests were carried out using the new version of the bio product, CaO_2 seed treatment, CaO_2 flood treatment, CaO_2 plus ZnO seed treatment, CaO_2 plus ZnO flood treatment, ZnO seed treatment, ZnO flood treatment and untreated control. There was no crown rotting and discoloration in any of the treatments. The root blackening in the control pots was only up to 30% in both the preplant flooded set and preplant dry sets of pots. This experiment will be repeated using cold water for flooding to create favorable conditions for symptom development.

Field Tests to Evaluate Products in 2016: Among the products tested in the field using micro-plots, none were able to protect against root mass blackening. However, the newer formulation of the bio product consistently showed clean crowns across replications in Hunter farm planted with the hybrid rice RTXL753. There were considerable crown discolorations and rotting in untreated control rice contained in micro-plots or free in the bar ditch (Table 2). The performance of the older bio product formulation was varied among replications. According to the manufacture, the new bio product has a second species of oxygenic photosynthetic bacteria. Because of the greater importance of crown health than root color, more tests will be carried out both in the greenhouse and field in the upcoming seasons. The field test at Hillemann was considered inconclusive due to delayed and inconsistent flood depth.

Evaluation of Cultivars for Resistance in 2016

The field was not flooded until later than normal due to rains. Even after flooding, there were a few dry spells. There was little variation in root mass blackening among the 20 rice cultivars grown in the Producers' Rice Evaluation Program (PREP) at Woodruff County. The root blackening ranged from 43% to 60%. However rice cultivars with brown discoloration and rotting ranged between 0% and 57%. Under such field situations, 8 of the 20 cultivars showed crown discoloration in more than 10% of the sampled plants, 6 cultivars from 5% to 10% and the remaining 6 from 0% to 3%. CLX1024, LaKast, RT 7311 CL, and RT XL753 did not show crown discoloration. There was some variation among replications. Some of the variability of crown symptoms may be due to differences in flood depth and soil types. In fields where the problem prevails frequently, autumn decline is more severe in the areas closer to cold irrigation water inlets and in places where the flood is deeper. A range of scores were taken in samples that showed different levels of severity (Table 3). Results show clear cultivar response differences. Some root systems may have better oxidative power than others. Root vigor, and the oxidation power of roots, may play a role in cultivar tolerance (Dobermann and Fairhurst, 2000). Cultivars with better root masses may also perform better in problematic fields. Root blackening is considered reversible with availability of oxygen; however, damage to the crown is irreversible. Although it has not been studied, late-maturing cultivars that are exposed to prolonged anaerobic/flooded conditions may exhibit more severe symptoms than early-maturing rice cultivars. Cultivar response may also vary from location to location.

Validating the New Cultivar Response Rating System

The fact that autumn decline was recorded using 2 rating scales (0 to 5 and 0 to 9), an index system that combines the 2 rating scales was developed in 2015. The index used a matrix to best describe the severity level in root mass discoloration and crown rot/discoloration. The matrix (Table 4) with descriptive rating scales (Table 5) appeared to best quantify the extent of damage. The crown rotting and discoloration is more damaging to the rice crop yield than just the root blackening, therefore, a double weight was assigned to the former. Moreover, to emphasize the importance of the irreversibility of crown rotting and discoloration to rice plants, a scale of 0 to 9 was assigned to evaluate damage in the crown. When the double weight values in a doubled (0 to 9) scale are added to the respective single weighted (0 to 5) scale root mass blackening, the numbers in the matrix range from 0 to 23. A rating of resistant (R) is represented by 0 to 2; moderately resistant (MR) by 3 and 4; moderately susceptible (MS) by 5 and 6; susceptible (S) by 7 and 8 and very susceptible (VS) by 9 to 23 (Table 6). Obviously a rice crop would be greatly affected if the crown discoloration rating goes more than 40% even if the blackening is only 10% or less. The matrix seemed well validated with the data obtained in 2016 and can be useful to evaluate response of rice cultivars grown in problematic fields.

Evaluation of Effect of Soil Drainage on New Root Growth in the Greenhouse

Rice plants showed growth of new roots when checked 24 h after drainage. New roots continued to grow until the fourth day (Table 6). However, after the fourth day, it was hard to pull the roots out of the dry soil. Besides, due to drought stress, the rice plants started to wilt and die. In this greenhouse study, rice plants were uprooted 4, 6, and 8 wk after permanent flood establishment and new root growth was detected at all growth stages. However, field conditions may be different from greenhouse. Therefore scouting for new root growth is recommended starting a day after drainage. Once the rice plants start to show new root growth, the field can be flooded again. Field sizes and capacities of water sources are important to decision making as to "how low" and 'how long" to keep the ground dry. It is important to note that the idea behind the drain and dry strategy is to allow oxygen into the soil similar to correction for straighthead problem in rice. While allowing oxygen into the soil, hydrogen sulfide gets oxidized and new roots grow. Drain and dry strategy is not an easy option where water is limited, especially to large fields where draining and re-flooding each take several days to complete.

Significance of Findings

Every year, from Arkansas rice production fields, we are receiving more reports on root blackening and crown rotting associated with autumn decline or hydrogen sulfide toxicity. 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 and alternative ways of managing the problem in various soil types 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 prevent significant losses that have occurred to some rice fields in previous seasons.

Acknowledgments

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Table 1. First greenhouse experiment testing products against autumn decline in 2015.

Treatment	Number of plants: Uprooted	Number of plants: Symptomatic	Symptomatic plants
			(%)
Control flooded	17	17	100
Bio product - old form.	15	4	27
H_2O_2	8	2	25
KNO_3	11	3	27
$KMNO_4$	16	7	44
Intermittent flushing[a]	20	11	55

[a] Rice plants were severely affected by water shortage due to the long flushing interval that appeared to weaken the plants and encourage the saprophytic fungi to grow in the crowns.

Table 2. Products tested in micro-plots in a field in Hunter, Ark., in 2016.

Product Name	Mean root mass discolored	Plants with crown rot	Crown rot
	-------------------(%)	-------------------	(0-9 scale)
Bio product - new form.	57	0	0
Bio product - old form.	74	27	1 to 5
Untreated check	73	43	2 to 9
Untreated bar ditch	90	100	9

Table 3. Rice cultivars evaluated for tolerance or resistance in a problem field for autumn decline in Hunter, Ark., in 2016.

Rice Cultivar	Mean root mass discolored	Plants with crown rot	Reps with crown rot	Crown rot
	------------------(%)	------------------	(No. out of 4)	(0-9 scale)
CLX1024	45	0	0	0
CLXP766	55	0	0	0
LaKast	48	0	0	0
XL753	58	0	0	0
XL760	50	2.5	1	2
CL163	48	3	1	3
CL272	53	5	2	5
Jupiter	45	5	1	2
Roy J	55	5	2	2
Titan	50	5	1	2 to 4
CL172	48	10	2	8
Thad	43	10	1	1 to 4
CL111	48	13	1	7 and 8
G214CL	60	15	3	1 to 8
Diamond	58	20	1	4 to 9
Mermentau	55	20	1	4 to 9
CLX1111	60	23	2	1 to 8
CLXL745	48	23	2	4
CL151	60	28	2	1 to 8
CL153	58	57	4	1 to 9

Table 4. 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	Rating	2X[a]	0 0	10% 1	25% 2	50% 3	75% 4	>75% >5
(%)	-- (0-9 scale)	--	-------------------------------		(%)		-------------------------------	
0	0	0	0=R	1=R	2=R	3=MR	4=MR	5=MS
10	1	2	2=R	6=MR	4=MR	5=MS	6=MS	7=S
20	2	4	4=MR	5=MS	6=MS	7=S	8=S	9VS
30	3	6	6=MS	7=S	8=S	9=VS	10=VS	11=VS
40	4	8	8=S	9=VS	10=VS	11=VS	12=VS	13=VS
50	5	10	10=VS	11=VS	12=VS	13=VS	15=VS	15=VS
60	6	12	12=VS	13=VS	14=VS	15=VS	16=VS	17=VS
70	7	14	14=VS	15=VS	16=VS	17=VS	18=VS	19=VS
80	8	16	16=VS	17=VS	18=VS	19=VS	20=VS	21=VS
90	9	18	18=VS	19=VS	20=VS	21=VS	22=VS	23=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.

Table 5. Rating scales used to rate crown discoloration and root discoloration in cultivars grown in soil with a history of autumn decline/hydrogen sulfide toxicity at Hillemann, Ark., in 2015.

Rating	Crown length discolored[a]	Rating	Root mass blackened[a]
(0-9 scale)	(%)	(0-5 scale)	(%)
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 > 0 = 10.

Table 6. Greenhouse test to evaluate effect of soil drainage on new root growth in field soil with a history of autumn decline.

4 wk after flood	Mean new root
day1	2
day2	3
day3	4
day4	5
6 wk after flood	
day1	2
day2	3
day3	6
8 wk after flood	
day1	6
day2	6
day3	7
day4	8

Economics of Fungicide Application for Rice Sheath Blight Disease in Arkansas

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Abstract

Sheath blight disease of rice caused by *Rhizoctonia solani* AG1-1A is one of the major diseases of rice in Arkansas. Fungicides are often recommended if the established threshold levels are reached and when sheath blight begins to threaten the upper canopy rice leaves during reproductive growth stages. The economic benefit of these applications must periodically be re-evaluated based on changes in cultivars, management practices, and fungicide efficacy. The effect of fungicide application timing was evaluated on the cultivars LaKast and Jupiter at two seeding rates. Fungicide timings consisted of an untreated control and application at panicle differentiation or boot split. All plots were artificially inoculated with the sheath blight fungus. Both fungicide application timings resulted in reduced sheath blight incidence and higher grain yields compared to the untreated control. However, mean monetary gains were variable based on trial location and fungicide application timing.

Introduction

Sheath blight is one of the major diseases of rice in Arkansas. It is caused by *Rhizoctonia solani* AG1-1A, a soilborne fungus that has several host plants. It also causes prominent diseases in corn and soybean. It prevails in any rice field under favorable conditions and nearly no field can be clean of this fungus. Prolonged periods of high humidity and high temperatures favor the initiation and progression of sheath blight disease of rice. The fungus survives as mycelia or a mycelial mass known as "sclerotia". These fungal structures are capable of floating on surfaces of flooded rice fields. The floating sclerotia, when in contact with the growing rice, infect the sheath at or just above the waterline. Infection primarily progresses upward through the canopy. However, it also progresses sideways to neighboring plants during physical contact of

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plant parts. Hence, rice fields with thick stands and/or those where excessive nitrogen has been applied encouraging vegetative growth often show severe sheath blight disease. In favorable environmental conditions, the disease usually starts between the panicle initiation (green-ring) and panicle differentiation (0.5-in. internode elongation) growth stages of the rice plant. Its development and spread can continue throughout the season if favored by weather. Therefore, scouting for sheath blight is recommended starting at green ring and needs to be continued to pre-heading. Due to the vertical progression of sheath blight disease in the plant canopy, short or semi-dwarf varieties can be damaged more severely than taller varieties in a short period of time. Likewise, due to its potential to progress in horizontal directions, rice cultivars that are leafy and form a closed canopy can create a favorable microenvironment for the development of disease.

Sheath blight disease has increased as production practices have increased inputs in Arkansas. Through years, the number of rice acres receiving fungicides appears to be increasing. Sheath blight is often well managed when using the integrated approach of planting tolerant cultivars and using best management practices. A one-time fungicide application is recommended only if the threshold warrants. The optimum fungicide treatment timing for Arkansas rice is often 7 to 14 days past panicle differentiation. A decision on fungicide application for sheath blight also depends on varietal susceptibility, height of the variety, favorability of the weather conditions, treatment thresholds and field management particularly associated with seeding and nitrogen fertilizer rates. To date, the commercially available and recommended fungicides for sheath blight in Arkansas have been proved to considerably slow down the disease progress. If fields are not well managed, a fungicide application may not be beneficial. More than one fungicide application to manage sheath blight alone has not been considered economical for Arkansas rice production.

Regardless of the threshold levels and the frequency of application recommended by the University of Arkansas System Division of Agriculture's Cooperative Extension Service for managing rice sheath blight, unneeded fungicide applications are not uncommon. These applications add additional expense for rice producers and at the same time risk the longevity of the fungicides through development of pathogen insensitivity. Although it is already known that several factors need to be considered to make the decision on fungicide application, the main objective of this study was to assess the monetary gains/losses of sheath blight control, with a one-time fungicide application, for alternative seeding rates and application timing related to rice developmental stages.

Procedures

In 2016, two trials were conducted at the University of Arkansas System Division of Agriculture’s Rice Research and Extension Center (RREC) near Stuttgart, Ark., and Pine Tree Research Station (PTRS) near Colt, Ark. Two cultivars, LaKast and Jupiter, were used to represent tall and short rice cultivars. Each cultivar was planted at both an optimum and maximum seeding rate of 72 and 109 lb/acre for LaKast and 73 and 111 lb/acre for Jupiter. Two fungicide application timings at panicle differentiation and boot split were evaluated. This resulted in a 2 × 2 × 2 factorial (cultivar × seeding rate × fungicide timing).

Trials were drill-seeded on 18 April and 6 May at the RREC and PTRS, respectively. Plot size was 8 rows on 7.5-in. spacing and 15-ft length. Plots at the RREC were artificially inoculated with fresh inoculum of *Rhizoctonia solani* Ag1-IA on 29 June at approximately the green ring growth stage of rice. The first fungicide application at the RREC was made on 12 July. Quadris fungicide (active ingredient azoxystrobin) was applied at 12.5 oz/acre at panicle differentiation. A second fungicide application was made to separate plots at boot split on 19 July. Treatments to plots at the PTRS were handled similarly to those at the RREC. Plots were inoculated on 12 July at the green ring stage. The first fungicide application was made on 24 July and the boot split application on 2 August. At both locations, slight sheath blight disease began to progress seven days after inoculation. Five disease readings were recorded: seven days after inoculation, seven days after the first fungicide application (DAA), 21 DAA, 28 DAA, and prior to harvest. Disease ratings included both vertical and horizontal sheath blight disease progress. A 0 to 9 scale was used to estimate the vertical disease progress where 0 indicates no disease and 9 indicates disease up to the panicle. Horizontal infection was estimated by the percentage of plants infected. Finally, disease index, grain yield, milling yield (whole kernel and total rice yields), and financial gain or loss were analyzed statistically using SAS v. 9.3 (SAS Institute, Inc., Cary, N.C.).

Monetary gains or losses associated with sheath blight disease control were calculated as gross returns (rice price × yield) less the cost of the fungicide application and cost of seed. A rice price of $4.75/bu was used in the analysis and represents the average U.S. farm price for rice for the months of August through October 2016 (USDA- NASS, 2016). The cost of fungicide application included both the cost of the fungicide itself and the cost of making one aerial fungicide application. Fungicide product cost was calculated at $2.06/oz for Quadris multiplied by the fungicide application rate (12.5 oz/acre). A cost of $7/acre was charged for custom aerial application. The cost of seed was calculated as the product of the seeding rates used for each cultivar multiplied by a seed price of $0.43/lb. Costs per unit for fungicide, seed, and aerial application were obtained from 2016 Arkansas crop enterprise budgets (Flanders and Watkins, 2016). Monetary gains attributable to date of fungicide application were calculated by location, cultivar, seeding rate, and cost of fungicide application. Monetary gains of sheath blight control were also analyzed statistically using PROC GLM in SAS v. 9.3. The study was arranged as a randomized complete block and means were separated using Fisher's protected least significant difference with $P = 0.05$.

Results and Discussion

Sheath blight disease progressed very slowly due to the hot and dry weather conditions. However, the disease reached its peak in unsprayed plots after a prolonged rainfall period in August. Due to clear differences in disease levels at the end of the season, only the sheath blight disease rating taken prior to harvest was used in the analysis. Typical issues with lodging generally associated with this disease were not noticeable due to the late advancement of the disease at both locations.

Significant differences in sheath blight disease levels were observed between sprayed and unsprayed plots in both cultivars at both locations. However, there was no significant difference between fungicide application timing for disease levels at either the RREC or PTRS (Figs. 1 and 2).

Jupiter produced significantly higher mean grain yields than LaKast at the RREC, but there was no yield difference at the PTRS (Table 1). Averaged across cultivars, the maximum seeding rate has not resulted in significantly higher grain yield compared to the optimum seeding rate at both locations. At the RREC and the PTRS, both fungicide application timings resulted in grain yields significantly greater than those in the untreated control. Milling yields, percent whole kernel rice, and total milled rice were significantly different between the cultivars at the RREC but not at the PTRS. There were no significant differences for percent whole kernel rice, and total milled rice based on cultivar, seeding rate, or fungicide spray timings at either location (Table 2).

The mean monetary gains are presented in Tables 3 and 4 for sheath blight control reported by cultivar, seeding rate, and fungicide spray timing at the RREC and PTRS. Also included in Tables 3 and 4 are mean gross returns, seed costs, and fungicide costs by variety, seeding rate, and fungicide spray timing. For the RREC, mean monetary gains varied by cultivar and by fungicide application timing (Table 3). Jupiter had greater mean monetary gains than LaKast at all seeding rate and spray timing comparisons, with maximum monetary gains occurring when fungicide was applied at boot split. Monetary gains were also maximized for LaKast when the seeding rate was optimum and fungicide was applied at boot split. However, under the maximum seeding rate, monetary gains for LaKast were numerically largest at the control (no spray). At the PTRS, monetary gains appeared to be numerically similar by cultivar across all seeding rate and fungicide timing combinations (Table 4). Monetary gains were higher numerically for both cultivars regardless of seeding rate with fungicide applied at panicle differentiation.

Statistical analysis results of differences in mean monetary gains are presented for both locations by cultivar, seeding rate, and fungicide spray timing in Table 5. Significant differences in mean monetary gains occurred by cultivar and by fungicide spray timing at RREC and by fungicide spray timing only at PTRS. Mean monetary gains were significantly larger for Jupiter than for LaKast at RREC. Mean monetary gains were also significantly larger for fungicide application at boot split when compared with the control (no spray). However, monetary gains were not significantly different between fungicide application at panicle differentiation and the control at RREC. At PTRS, mean monetary gains varied significantly only for fungicide spray timing. Mean monetary gains were significantly larger for fungicide application at panicle differentiation when compared to the control. However, mean monetary gains for fungicide application at boot split were not significantly different from those for the control.

This is the first year of the study and it will be repeated in 2017 and 2018. Had the sheath blight disease progressed earlier in the season, it may have had a greater effect on the crop causing weak stems and subsequently lodging. In such situations, yield in unsprayed plots could have been considerably reduced and grain quality affected. Therefore, the results of this study are considered preliminary and tests will be repeated. In some years, weather factors such as heavy rain storms, strong wind, and management practices such as excessive nitrogen fertilization increase sheath blight disease resulting in significant losses. Although there was no significant grain yield difference between the two fungicide spray timings, both timings resulted in increased grain yields compared to the untreated control. These results suggest the current recommended fungicide application timing of panicle differentiation through heading is generally appropriate for use in Arkansas.

Significance of Findings

Even if threshold levels and the frequency of application have been recommended already by the University of Arkansas System Division of Agriculture's Cooperative Extension Service for managing sheath blight disease in rice, the economic benefit of these applications must periodically be re-evaluated based on changes in cultivars, management practices, and fungicide efficacy. Unneeded fungicide applications add additional expense on rice producers and at the same time risks the longevity of the fungicides associated with development of pathogen insensitivity.

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Table 1. Differences in mean yields from sheath blight control by variety, seeding rate, and spray timing, University of Arkansas System Division of Agriculture's Rice Research and Extension Center and Pine Tree Research Station, 2016.

Class	RREC[†]	PTRS
	----------- (bu/acre)	-----------
Variety		
LaKast	164.2 B[‡]	173.3 A
Jupiter	185.5 A	165.6 A
LSD	7.5	8.1
Seeding rate		
Optimum	174.5 A	166.4 A
Maximum	175.2 A	172.5 A
LSD	7.5	8.1
Spray timing		
No spray	164.2 B	158.0 B
PD	177.6 A	179.9 A
BS	182.7 A	170.4 A
LSD	9.2	9.9

[†] RREC = Rice Research and Extension Center, Stuttgart; PTRS = Pine Tree Research Station, near Colt; LSD = least significant difference; PD = panicle differentiation; and BS = boot split.

[‡] Means within a column followed by different letters are significantly different at the *P* = 0.05 level.

Table 2. Differences in mean total percent and head yield milling from sheath blight control by variety, seeding rate, and spray timing, University of Arkansas System Division of Agriculture's Rice Research and Extension Center and Pine Tree Research Station, 2016.

Class	RREC†		PTRS	
	TYD	HYD	TYD	HYD
Variety				
LaKast	68.2 A‡	54.6 A	67.9 A	54.3 A
Jupiter	70.6 B	56.5 B	68.2 A	54.6 A
LSD	0.72	0.58	1.1	0.88
Seeding rate				
Optimum	69.6 A	55.7 A	68.1 A	54.5 A
Maximum	69.2 A	55.5 A	68.0 A	54.4 A
LSD	0.72	0.58	1.1	0.88
Spray timing				
No spray	69.4 A	55.5 A	68.0 A	54.4 A
PD	69.0 A	55.4 A	68.3 A	54.7 A
BS	69.6 A	55.6 A	67.9 A	54.3 A
LSD	0.89	0.71	1.35	1.08

† RREC = Rice Research and Extension Center, Stuttgart; PTRS = Pine Tree Research Station, near Colt; LSD = least significant difference; PD = panicle differentiation; BS = boot split; TYD = total rice yield; and HYD = head rice yield.

‡ Means within a column followed by different letters are significantly different at the *P* = 0.05 level.

Table 3. Monetary gains of sheath blight control by variety, seeding rate, and spray timing, University of Arkansas System Division of Agriculture's Rice Research and Extension Center, 2016.

Variety	Seeding rate	Spray timing†	Gross return	Seed cost	Fungicide cost	Monetary gain
			($/acre)			
LaKast	Optimum	No spray	762.78	30.96	0.00	731.82
		PD	794.77	30.96	32.73	731.08
		BS	867.41	30.96	32.73	803.72
	Maximum	No spray	786.55	46.87	0.00	739.68
		PD	809.20	46.87	32.73	729.60
		BS	744.59	46.87	32.73	664.99
Jupiter	Optimum	No spray	808.86	31.82	0.00	777.04
		PD	878.34	31.82	32.73	813.80
		BS	952.36	31.82	32.73	887.81
	Maximum	No spray	819.44	47.73	0.00	771.71
		PD	954.86	47.73	32.73	874.40
		BS	971.19	47.73	32.73	890.73

† No spray = control; PD = panicle differentiation; and BS = boot split.

Table 4. Monetary gains of sheath blight control by variety, seeding rate, and spray timing, University of Arkansas System Division of Agriculture's Pine Tree Research Station, 2016.

Variety	Seeding rate	Spray timing[†]	Gross return	Seed cost	Fungicide cost	Monetary gain
			($/acre)			
LaKast	Optimum	No spray	810.10	30.96	0.00	779.14
		PD	886.79	30.96	32.73	823.10
		BS	776.71	30.96	32.73	713.02
	Maximum	No spray	786.11	46.87	0.00	739.24
		PD	903.15	46.87	32.73	823.55
		BS	868.46	46.87	32.73	788.86
Jupiter	Optimum	No spray	710.81	31.82	0.00	678.99
		PD	843.76	31.82	32.73	779.21
		BS	801.88	31.82	32.73	737.33
	Maximum	No spray	749.60	47.73	0.00	701.87
		PD	848.09	47.73	32.73	767.63
		BS	851.03	47.73	32.73	770.57

[†] No spray = control; PD = panicle differentiation; and BS = boot split.

Table 5. Differences in mean monetary gains of sheath blight control by variety, seeding rate, and spray timing, at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC) and Pine Tree Research Station (PTRS), 2016.

Class	RREC	PTRS
	($/acre)	
Variety		
LaKast	733.48 B[†]	777.82 A
Jupiter	835.92 A	739.27 A
LSD[‡]	36.35	39.28
Seeding rate		
Optimum	790.88 A	751.80 A
Maximum	778.52 A	765.29 A
LSD	36.35	39.28
Spray timing		
No spray[§]	755.06 B	724.81 B
PD	787.22 BA	798.37 A
BS	811.82 A	752.44 AB
LSD	44.52	48.11

[†] Means within a column followed by different letters are significantly different at the P = 0.05 level.
[‡] LSD = least significant difference.
[§] No spray = control; PD = panicle differentiation; and BS = boot split.

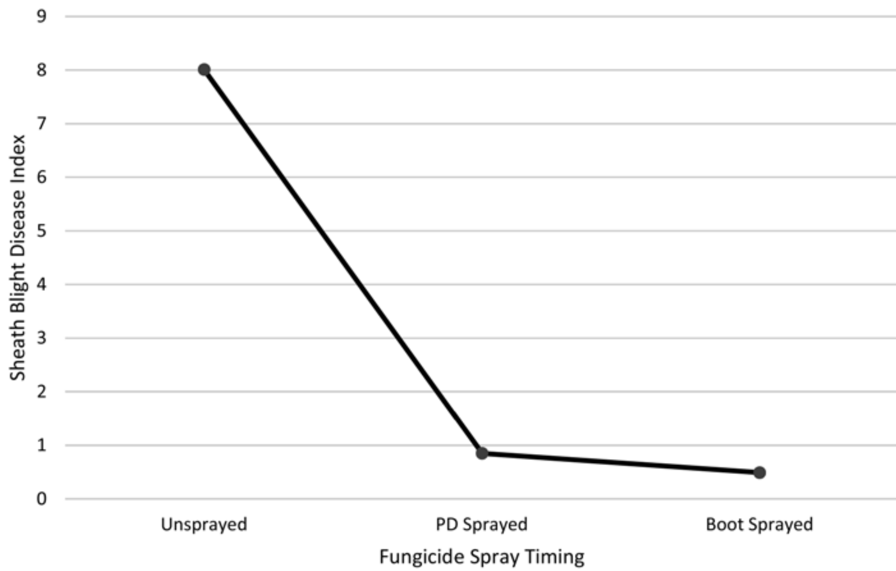

Fig. 1. Sheath blight disease index (IND) as affected by spray timing in rice varieties Lakast and Jupiter at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC), Stuttgart, Ark., in 2016. PD = panicle differentiation.

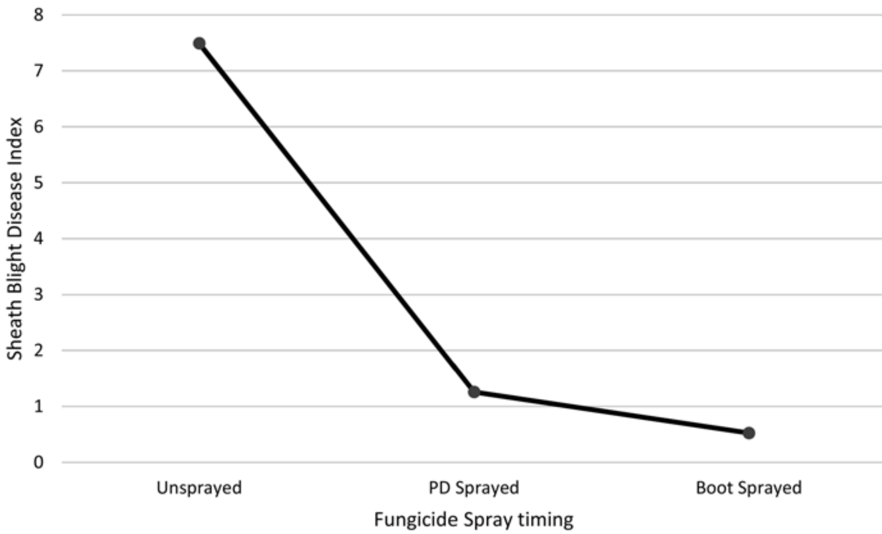

Fig. 2. Sheath blight disease index as affected by spray timing in rice varieties Lakast and Jupiter at the University of Arkansas System Division of Agriculture's Pine Tree Research Station near Colt. Ark., in 2016. PD = panicle differentiation.

Analysis of Variation in Sweep Net Technique in Rice

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Abstract

Although the method for determining damage to rice using cage studies is fairly standardized, how that damage translates to the number of stink bugs caught using a sweep net may vary due to a number of factors. Understanding the differences in sweep net monitoring that exist among consultants, producers, and researchers could lead to an increased accuracy of decision-making for rice stink bug control. The objective of this study was to determine whether variation in sweep net technique existed, and to determine what factors played a role in these differences. A large amount of variation was found in sweep length, which was related to the number of stink bugs caught. However, sweep length combined with other factors only explained 42% of the variation in the number of rice stink bugs caught.

Introduction

The threshold for rice stink bug (RSB) has changed recently in states such as Mississippi and Louisiana (Awuni et al., 2015), although Arkansas's threshold has remained static. Thresholds for all of these states are based upon similar methods of determining damage to rice, however, the estimation of how this damage relates to field sampling is less clear (Rashid, 2003; Blackman, 2014; Awuni et al., 2015). The current recommendation for sweeping rice stink bugs is to take 180° degree sweeps with a 15-in. sweep net, with the top of the net just at the top of the rice heads (Hardke, 2013). Thresholds are based off the assumption that producers and consultants use these recommended sweeping techniques. However, consultants, producers, and researchers generally do not follow these techniques closely, instead sweeping as they would in soybeans or however they were taught (pers. observations). Significant differences in

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technique could lead to less accurate thresholds, and overall poor control of the rice stink bug. The objective of this study was to determine whether variation in sweep net technique existed, and to determine what factors played a role in this variation.

Procedures

Experiments were conducted in producer fields that had rice stink bug populations, with no preference to cultivar. Eight fields in total were analyzed in the summer of 2016 for this study. At least 3 sweepers were observed within each field, and for each person sweeping, a partner followed behind and recorded the length of the sweep. Measurement of sweep length was considered the distance from the center of the sweeper to the edge of the net when it exited the crop canopy. To record the sweep length, sweepers took 2 sets of 5 consecutive sweeps, with the left and then the right distance recorded at the end of the two sets of 5 sweeps. At the end of each set of 5, the number of rice stink bugs captured was counted and recorded.

Along with the sweep distance measurement, data relating to the field being swept and each individual sweeper was also recorded for each field. The approximate growth stage of the field, the approximate height of the crop canopy, and the weediness of each block was recorded within the field. For each sweeper within a field, the height of the sweeper, experience level of each sweeper, numbers of rice stink bugs captured, and sweep length was also recorded. A total of the left and right sweep lengths was considered the sweep length of each replication. This total of each replication was then paired with the total rice stink bugs caught from the 2 sets of 5 sweeps.

For each field sampled, 3 to 4 areas were chosen to be blocks containing each set of sweepers. These blocks were at least 10 ft (9 m) from the edge of the field and a greater distance was left between each block. In each field and within each block, the assignment of sweeper location was randomized using a randomized complete block design. Data was then assessed using regression analysis with PROC REG SAS v. 9.3 (SAS Institute, Inc., Cary, N.C.). Single regression analysis was used to analyze the relationship between the height of the sweeper and the width of their sweep, and also the width of the sweep and the number of stink bugs caught. Multiple regression analysis was used to understand the amount of variation among the number of stinkbugs caught that could be explained by sweep length, sweeper height, and the height of the canopy.

Results and Discussion

Sweep length ranged from 31 to 108 inches and averaged 76.1 inches over 130 sets of 10 sweeps (Table 1). The height of the sweepers ranged from 61 to 74 inches and averaged 68.19 inches. The relationship between sweeper height and sweep length was not significant with a *P*-value of 0.2030 and an R^2 value of 0.012 (Fig. 1). An average of 21.32 rice stink bugs were caught per 10 sweeps, and the 10 sweep catches ranged from 1 to 144 rice stink bugs (Table 1). The relationship between the sweep length and the number of stink bugs caught was significant at $P < 0.0001$ and an R^2 value of 0.219 (Fig. 2). Although this relationship was significant, sweep length explained less than 23% of the variation in the number of rice stink bugs caught.

A model containing sweep length, sweeper height, and canopy height as predictive variables was used to try to explain the variation seen in the number of RSB that were caught (Table 2). Overall, 42% of the variation was explained with an R^2 value of 0.42, and only sweeper height was not significant. A large amount of variation is still left to be explained due to variables that have yet to be quantified, although it is clear that sweep length plays a significant role.

Significance of Findings

Studies continue to use a designated sweep length as a basis for translation of damage observed in cage studies to thresholds determined by rice stink bug catch per sweep. The findings from this study show that there is a large amount of variability in sweep length found among researchers and consultants. This study also shows that when the sweep length was accounted for along with two other variables, a large amount of variation in the number of rice stink bugs caught still was not explained. This means that other factors likely need to be controlled for thresholds to translate properly. Determining factors that affect sweeper variability may help to refine our thresholds and help educate clientele on proper sweeping techniques, which in the end will help them in making the right decision on when stink bug control is warranted.

Acknowledgments

This research was 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 would like to thank the rice producers in Central and Eastern Arkansas that allowed us to use their fields for this study.

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Table 1. Variation in sweep net sampling.

Variable recorded	Average	Range	Standard error
Sweep length (inches)	76	31-108	1.6
RSB† caught per 10 sweeps	21	1-144	2.0
Canopy height (inches)	41	32-44	0.2
Sweeper height (inches)	68	61-74	0.4

† RSB = rice stink bug.

Table 2. Multiple regression analysis of the number of rice stink bugs caught as the dependent variable.

Model	Parameter estimate	Standard error	*t*-value	*P*-value
Sweep length	0.60	0.1	6.9	<.0001
Canopy height	4.10	0.6	6.9	<.0001
Sweeper height	0.01	0.4	0.03	0.9783

Dependent variable: RSB† caught per 10 sweeps
Adj. R-Square = 0.42

† RSB = rice stink bug.

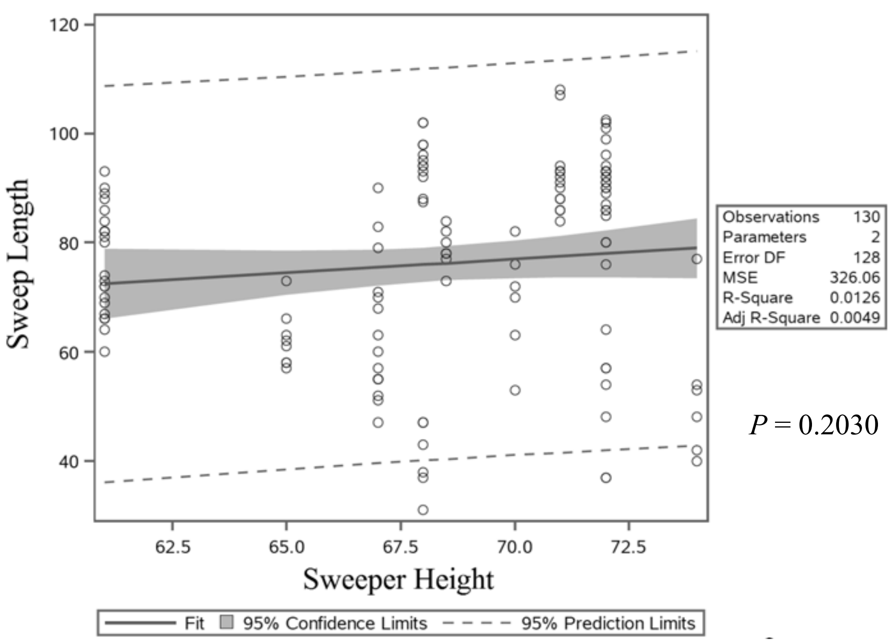

Fig. 1. Regression analysis of sweeper height and sweep length.

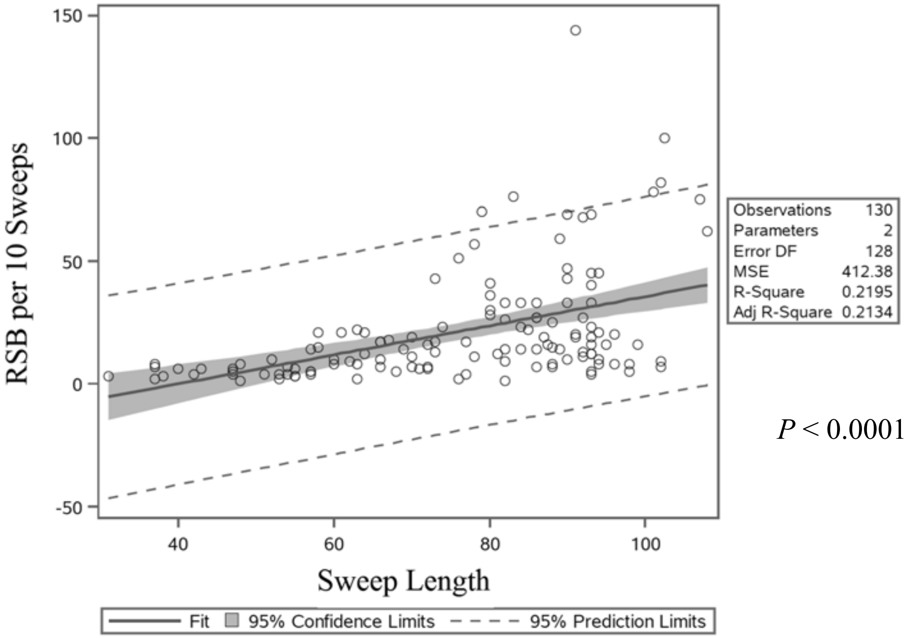

Fig. 2. Regression analysis of sweep length and the number of rice stink bugs caught per 10 sweeps.

Evaluation of Rice Stink Bug, *Oebalus pugnax*, Damage to Maturing Rice Kernels

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Abstract

This study sought to determine the grain maturity level at which rice, *Oryza sativa* L., is no longer susceptible to damage from rice stink bug, *Oebalus pugnax* (Fabricius), feeding. Data from this study indicates that rice is susceptible to damage through 60% of the hard dough stage, and that rice stink bug damage is significantly reduced between 60% to 80% of the hard dough stage.

Introduction

The rice stink bug, *Oebalus pugnax* (Fabricius) (Hemiptera: Pentatomidae), is a major pest of rice (*Oryza sativa* L.) grown in Arkansas and many other southern states (Webb, 1920). The rice stink bug feeds on the developing kernels of rice and other grasses beginning at the heading phase when the panicle is exerted from the boot until the end of the ripening phase, known as hard dough (Swansom and Newsom, 1962). Feeding by the rice stink bug in the early stages of heading, especially emergence and flowering, can cause blanked kernels and direct rough-rice mass loss (Swanson and Newsom, 1962; Bowling, 1963; Espino et al., 2007). At the later stages of heading, which are milk through soft and hard dough, feeding by the rice stink bug is associated with broken, chalky or pecky kernels. Pecky kernels can be a result of feeding by the rice stink bug, because the kernel is left more susceptible to invasion by fungi that are both present on the stinkbug itself and already present in the rice field (Ryker and Douglas, 1938). If a high occurrence of pecky kernels is observed when rice is being sold, a USDA grade reduction is likely (Swanson and Newsom, 1962; Bowling, 1963; Espino et al., 2007).

Rice is most susceptible to rice stink bug damage during the milk and soft dough stages (Espino et al., 2007); however, the question of when rice stink bugs are no longer

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capable of causing significant yield loss or damage is less clear. It has been shown that rice stink bugs can damage the rice plants in the soft dough stage and into the hard dough stage (when the kernels are considered mature) by causing an increase in pecky rice (Harper et al., 1993; Patel et al., 2006). However, it is unknown at what percentage of hard dough rice stink bugs are no longer capable of significantly damaging rice. This is important because consultants and producers often spray for significant populations of rice stink bug during hard dough, even though the past recommendation has always been "Hard dough, let it go" (Gus Lorenz, pers. comm.). Consultants and producers typically encounter issues concerning re-entry intervals (REI) and post-harvest intervals (PHI) when they apply insecticides late in hard dough stage, but the fear of losses due to peck drive this decision-making process.

The objective of this study was to determine the stages of hard dough that are susceptible to damage from rice stink bug feeding through the formation of pecky kernels.

Procedures

Field plots were located at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center near Stuttgart, Ark., utilizing both hybrid (XL753) and conventional (Diamond) rice cultivars. Plots were 70 × 63 inches using a 7-inch drill spacing and were maintained using standard agronomic practices. Applications of Karate with Zeon Technology® (Syngenta AG, Basel, Switzerland) at 1 ounce per acre were applied using a CO_2 canister backpack sprayer when heading initiated. This application of insecticide, and subsequent applications each week, was utilized to ensure plots did not accumulate high levels of peck before cages were added. Insecticide applications were terminated a few days before hard dough stage was reached, and sleeve cages were then added to panicles at prescribed hard dough percentages of 20%, 40%, 60%, 80%, and 100% hard dough. Sleeve cages used were white insect rearing sleeves, 20 × 40 cm (BioQuip Products, Rancho Dominguez, Calif.). A bamboo rod was utilized to hold the sleeve cage and rice plant up due to the weight of the cages, and the cage and rice plant were zip-tied to the bamboo pole. Cages were randomly placed in the field as individual panicles reached one of the designated percentages of hard dough. Stinkbugs were then infested at appropriate timings. It is important to note that the hard dough infestation timings in the hybrid cultivar were spaced over a longer period of time from the infestation of 20% to 100% (15 August 2016 – 26 August 2016) than the conventional cultivar (20 September 2016 to 23 September 2016). This is due to a difference in planting dates, different rates of growth between the two cultivars, and a cold spell that occurred during the early portions of the hard dough stage in the hybrid cultivar.

Adult and late-instar rice stink bug nymphs caught with sweep nets from heading rice and weedy grasses were utilized for this study. To ensure viability of the individuals for the study, insects were given fresh plant material, moist paper towels, and cotton balls soaked in sugar water, and kept at 75 °F for at least 24 hours prior to utilization in sleeve cage trials. Healthy looking adults and late-instar nymphs were then added to sleeve cages. Mortality within each cage was checked 24 hours after introduction, and then every 48 hours after that and replaced as needed.

The experiment design included 3 factors: number of rice stink bugs in the sleeve cage (0 or 2), the percent hard dough when stink bug infestations were initiated (20%, 40%, 60%, 80%, 100%), and the rice cultivar. For each combination of infestation level × infestation timing × cultivar, 10 replications were performed. Panicles for this experiment were chosen based on their individual growth stage. Infestation levels were then assigned randomly once a hard dough percentage was determined for each random panicle, with no single rice plant receiving more than one cage.

At the time of harvest, panicles contained inside the sleeve cages were removed, put in paper bags, and placed in a dryer until moisture was at 12%. Panicles were removed from the paper bags and sleeve cages, and rough rice kernels were removed. The rough rice kernels from each panicle were then de-hulled and brown rice was observed with a light box to determine peck. Samples were weighed, sorted by damage, and then a percentage of pecky kernels by weight was then determined. Data was then analyzed using an analysis of variance, PROC MIXED, SAS v. 9.3 (SAS Institute, Inc., Cary, N.C.) with means separated using Tukey's honestly significant difference (HSD) post hoc analysis (P = 0 0.05). Data was also combined across the two cultivars using a two-way analysis of variance, PROC MIXED, SAS v. 9.3 (SAS Institute, Inc., Cary, N.C.) with means separated using Tukey's HSD post hoc analysis ($P = 0.05$).

Results and Discussion

The percentage of peck observed ranged from 0.03% to 21.45% in the hybrid cultivar and 2.49% to 6.98% in the conventional cultivar (Table 1). There was significantly more peck observed at the 20% to 40% hard dough stage infestation timings when compared to the 80% to 100% infestation timings in both cultivars. There was also no significant difference in the amount of peck found at 80% and 100% hard dough stage when compared to the untreated check, for both cultivars. When comparing the two cultivars, significant differences were observed between infestation timings (Table 2). The 20%, 40%, and 60% hard dough infestation timings exhibited significantly more peck in the hybrid cultivar than the conventional cultivar, although no differences were seen at the 80% and 100% hard dough infestation timings.

When the data was combined across the two cultivars, the percentage of peck observed ranged from 13.83% to 1.38% (Table 3). Significantly more peck was observed at the 20% to 40% hard dough infestation timings when compared to the 80% and 100% infestation timings. Neither the 80% or 100% hard dough infestation timing was found to have a significant difference in peck when compared to the untreated checks. When the amount of peck found was combined across the two cultivars, a similar trend in the percentage of peck found from the cultivars alone was observed (Tables 1 and 3). Differences between cultivars were likely due to temperature differences during infestation timings.

Significance of Findings

In this study, it was clear that in both cultivars the rice stink bug caused a significant amount of peck at the 20% to 60% hard dough stage, and very little peck at the

80% and 100% hard dough stage. This indicates that rice is likely susceptible to attack from the rice stink bug through 60% hard dough stage, and insecticidal applications should be terminated somewhere between 60% and 80%. Future studies will utilize large cages and real-world infestation levels to determine the amount of damage caused from 20% to 80% hard dough stage and to better define the cutoff time for insecticide applications.

Acknowledgements

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Table 1. Percent peck in brown rice at 2 rice stink bugs per panicle (n = 199).

Cultivar	Timing	Peck
		(%)
Hybrid	20% hard dough	21.45 a†
	40% hard dough	13.89 b
	60% hard dough	12.25 b
	80% hard dough	0.03 c‡
	100% hard dough	1.69 c‡
Conventional	20% hard dough	6.98 a
	40% hard dough	4.84 ab
	60% hard dough	3.81 ab
	80% hard dough	2.49 bc‡
	100% hard dough	2.71 bc‡

† Peck percentages within each cultivar followed by the same lowercase letter are not significantly different at *P* = 0.05 using Tukey's honestly significant difference (HSD) post hoc analysis.

‡ Peck percentage is not significantly different than the 0 infestation level at *P* = 0.05 using Tukey's HSD post hoc analysis.

Table 2. Comparison of peck percentages between the hybrid and conventional cultivar (n = 199).

Cultivar	Timing	Peck
		(%)
Hybrid	20% hard dough	21.45 a†
Hybrid	40% hard dough	13.89 ab
Hybrid	60% hard dough	12.25 bc
Conventional	20% hard dough	6.98 bcd
Conventional	40% hard dough	4.84 cd
Conventional	60% hard dough	3.81 d
Conventional	100% hard dough	2.71 d
Conventional	80% hard dough	2.49 d
Hybrid	100% hard dough	1.69 d
Hybrid	80% hard dough	0.03 d

† Peck percentages within each cultivar followed by the same lowercase letter are not significantly different at *P* = 0.05 using Tukey's honestly significant difference post hoc analysis.

Table 3. Percent peck in brown rice when combined across cultivars (n = 199).

Timing	Infestation level	Peck
		(%)
20% hard dough	2	13.83 a[†]
40% hard dough	2	9.37 ab
60% hard dough	2	8.03 b
80% hard dough	2	1.38 c[‡]
100% hard dough	2	2.20 c[‡]

[†] Peck percentages within each cultivar followed by the same lowercase letter are not significantly different at $P = 0.05$ using Tukey's honestly significant difference (HSD) post hoc analysis.

[‡] Peck percentage is not significantly different than the 0 infestation level at $P = 0.05$ using Tukey's HSD post hoc analysis.

Effect of Rice Stink Bug, *Oebalus pugnax*, on Rice Quality and Yields

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Abstract

The objective of this study was to determine the amount of damage that increasing densities of rice stink bug (RSB) could cause to the different developmental stages of rice. No significant difference was found for any of the rice stink bug density and timing combinations using the following metrics: the percent whole kernel milled rice, percent total milled rice yield, and blank kernels. The only significant difference in yield was observed at the soft dough stage; however, the significantly lower yield was not consistent across increasing RSB infestation levels. Significantly more damaged kernels were only observed at the milk stage infestation timing, although damage attributed to rice stink bug feeding increased significantly with increasing RSB density at the bloom, milk, and hard dough infestation timings. Overall, an increase in rice stink bug damaged kernels was observed for most of the rice heading growth stages, but a trend in direct yield affects from rice stink bug feeding was not observed.

Introduction

The rice stink bug, *Oebalus pugnax* (F.), is a pest of rice that feeds upon developing grains using piercing-sucking mouthparts. Feeding by the rice stink bug (RSB) during the early stages of rice development can cause kernels to become severely shrunken, or be completely blanked altogether. When feeding occurs later in the grain fill process, an area of chalky discoloration at the feeding site is often formed. This discoloration is known as 'pecky' rice and is caused by the invasion of fungi into developing rice kernels after the RSB has pierced the rice kernels during feeding attempts (Swanson

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and Newsom, 1962, Hollay et al., 1987). The rice inspection handbook allows for no more than 0.5% damaged grain, which includes pecky rice, in a 500-g sample to be considered U.S. grade 1 (USDA-FGIS, 2009). Grade reductions due to increased amounts of damaged kernels can lead to large, irreversible losses to the value of the grain after it has been harvested.

Clayton et al. (2016) observed significantly more damage to milk stage rice at RSB densities of 0.26/ft^2 and above compared to the non-infested control at 0.13 RSB/ft^2. Espino et al. (2007) also found significant amounts of RSB damage at the soft dough infestation timing, although much greater RSB densities were used. The question of when RSB needs to be controlled is still contested, with reports such as Espino et al. (2007) and Awuni et al. (2015) directly contradicting each other. The objective of this study was to determine the amount of damage that increasing densities of RSB are able to cause to different growth stages of rice. The purpose of this study was to compliment data from Clayton et al., 2016, using higher infestation levels with the identical methods.

Procedures

Experiments were conducted at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center near Stuttgart, Ark. The cultivar Diamond was drill-seeded 26 April 2016 and grown according to standard agronomic practices for Arkansas. Plots were 9 rows on 7-inch drill spacing and 70 inches in length.

Cages were placed over plots prior to heading and sprayed with a foliar insecticide application of Karate Z® (Syngenta Agrochemical Company, Basel, Switzerland) to prevent natural infestations of RSB and remove any insects present. When individual plots reached >50% of the plants at one of the desired stages of kernel development—flowering, milk, soft dough, or hard dough—RSB infestations were made. The desired number of RSB were placed in small foam cups and placed in the rice canopy and allowed to move freely. Infested cages were checked daily and RSB were allowed to remain for 7 days, after which infestations were terminated with foliar insecticide sprays. Cages were kept in place until harvest. Infestation levels were 0, 42, 84, and 168 RSB/plot, or a density of 0, 1.37, 2.75, and 5.49 RSB/ft^2, respectively. This experiment was designed as a randomized complete block with four 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, a cotton ball soaked in sugar water, and a moist paper towel in a laboratory at 75 °F for 24 h prior to infestation in field cages. Cage frames were 6 ft^3 made of 1-inch PVC pipe with 20 × 20 amber fabricated coverings (Lumite, Inc., Alto, Ga.).

Ten rice panicles were removed before harvest and placed in a brown paper bag and stored in a dryer until moisture was 12%. These panicles were harvested by hand and separated into kernels and blanks (unfilled kernels), with partial filled kernels counted as kernels. Blanks and seed were counted and the percentage for 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 moisture was 12%. A random 100-g sample of seed harvested with the plot combine was dehulled for examination using a light box. Seed was separated into undamaged, RSB 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).

Results and Discussion

A significant difference in percentage of damaged kernels was observed between RSB densities when infested at the rice milk development stage, although no other differences were observed in the percentage of damaged kernels ($P < 0.10$, Table 1). All RSB infestation levels were found to have a higher percentage of damaged kernels than the control. RSB densities of 5.49/ft^2 had the largest percentage of damaged kernels, with RSB densities of 1.37 or 2.75/ft^2 being significantly lower. In a similar study, Awuni et al. (2015) found significantly greater damaged kernels at RSB densities of 0.84 and 1.67/ft^2 using large cages. Espino et al. (2007) found that at densities of 15.79 RSB/ft^2, differences were observed between the amount of damaged rice when infestations were made at bloom, milk, and soft dough stages. This differed from our trial, likely due to the large difference in RSB density used by Espino et al. (2007), however, Awuni et al. (2015) found significant increases of damaged kernels at comparable infestation densities.

Differences were observed for damaged kernels attributed specifically to RSB feeding at the bloom, milk, and hard dough infestation timings (Table 2). At both the bloom and milk infestation timings, 5.49 RSB/ft^2 had more RSB damage than any other RSB density and the untreated check. Also, there were more RSB damaged kernels than the untreated check at the milk infestation timing with 2.75 RSB/ft^2. No differences were observed at the soft dough infestation timing, and all RSB densities exhibited more RSB damaged kernels compared to the untreated check at the hard dough infestation timing.

Differences were observed in grain yield only at the soft dough infestation timing, but considering that only the 1.37 RSB/ft^2 exhibited a yield response, this did not indicate a response to RSB infestation density (Table 3). Awuni et al. (2015) reported a significant grain yield decrease in plots infested with 0.84 and 1.67 RSB/ft^2 compared to the control in their large cage experiments and greenhouse experiments. Clayton et al. (2016) found no significant difference in grain yield at any timing or infestation level.

No differences in the percentage of blank kernels were observed (Table 4). Blackman (2014) observed similar results with no increase in unfilled kernels with densities ranging from 0.15 to 3.0 RSB/ft^2. However, Espino et al. (2007) found significantly higher amounts of unfilled kernels at heading when compared to soft dough and uninfested controls, although much greater RSB infestation levels were utilized when compared to both Blackman (2014) and this study.

No significant difference was observed in total milled rice and whole kernel milled rice (Tables 5 and 6). These results are comparable to Clayton et al. (2016) and Espino et al. (2007), where no differences in total milled rice yield were observed. Bowling (1963) however found a decrease in total milling yields with increased RSB densities.

Averaged across infestation timings, RSB density exhibited a significant effect on percent damaged kernels and percent RSB damaged kernels (Table 7). All RSB densities resulted in greater levels of damaged kernels when compared to the untreated check, with 5.49 RSB/ft^2 having significantly more damaged kernels than all other levels. Increasing RSB density results in greater RSB damaged kernels. Averaged across infestation timings, there were no differences based on RSB infestation density for grain yield, blank kernels, total milled rice yield or whole kernel milled rice yield.

Overall, an increase in rice stink bug damaged kernels was observed for most of the rice heading growth stages, but a trend in direct yield affects from rice stink bug feeding was not observed. This differs from findings from other studies that used similar RSB infestation densities, especially findings by Awuni et al. (2015). This data combined with increased understanding of RSB sampling will help to further understand the density of RSB that is able to warrant an economic response.

Significance of Findings

The rice stink bug is an important economic pest to rice growers. It is imperative that the University of Arkansas System Division of Agriculture's Cooperative Extension Service provides growers with an effective 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 growers. The results of this study will help to refine and improve the existing threshold for rice stink bug in Arkansas.

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.

Infestation density	Bloom	Milk	Soft dough	Hard dough
(ft^2)		(%)		
0	2.35	3.05 c[†]	4.58	2.48
1.37	2.50	3.94 b	4.23	4.07
2.75	2.63	4.25 b	5.18	3.56
5.49	2.88	5.21 a	5.11	3.62
$LSD_{0.10}$[‡]	NS	0.84	NS	NS
CV[§]	23.65	15.68	12.50	24.33

[†] Means followed by the same letter within a column are not significantly different ($P < 0.10$).
[‡] LSD = least significant difference.
[§] CV = coefficient of variation.

Table 2. Percent rice stink bug damaged kernels based on weight in a 100-g brown rice sample for each rice growth stage and rice stink bug infestation density.

Infestation density	Bloom	Milk	Soft dough	Hard dough
(ft^2)		(%)		
0	0.73 b[†]	0.97 c	0.96	0.73 b
1.37	0.95 b	1.36 bc	1.06	1.26 a
2.75	0.95 b	1.77 b	2.06	1.32 a
5.49	1.26 a	2.95 a	1.44	1.60 a
$LSD_{0.10}$[‡]	0.31	0.49	NS	0.40
CV[§]	24.71	21.36	42.12	22.46

[†] Means followed by the same letter within a column are not significantly different ($P < 0.10$).
[‡] LSD = least significant difference.
[§] CV = coefficient of variation.

Table 3. Grain yield (bu/acre) for each rice growth stage and rice stink bug infestation density.

Infestation density	Bloom	Milk	Soft dough	Hard dough
(ft^2)	-----------------	---------(%)---------	-----------------	-----------------
0	175.2	168.1	166.0 a[†]	119.1
1.37	169.6	170.1	153.5 b	121.8
2.75	179.8	158.7	168.8 a	117.1
5.49	164.7	160.8	161.9 a	120.4
$LSD_{0.10}$[‡]	NS	NS	7.00	NS
CV[§]	5.42	6.32	3.32	11.09

[†] Means followed by the same letter within a column are not significantly different ($P < 0.10$).
[‡] LSD = least significant difference.
[§] CV = coefficient of variation.

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.

Infestation density	Bloom	Milk	Soft dough	Hard dough
(ft^2)	-----------------	---------(%)---------	-----------------	-----------------
0	15.82	21.26	24.05	35.21
1.37	21.49	20.44	19.77	46.18
2.75	20.15	21.88	25.82	46.25
5.49	16.67	18.43	25.79	46.53
$LSD_{0.10}$[†]	NS	NS	NS	NS
CV[‡]	24.07	25.96	22.71	36.28

[†] LSD = least significant difference.
[‡] CV = coefficient of variation.

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

Infestation density	Bloom	Milk	Soft dough	Hard dough
(ft^2)	-----------------	---------(%)---------	-----------------	-----------------
0	15.82	21.26	24.05	35.21
0	70.06	72.65	71.14	66.70
1.37	71.13	72.64	71.10	66.79
2.75	71.62	71.19	70.82	66.24
5.49	70.91	71.82	70.37	65.73
$LSD_{0.10}$[†]	NS	NS	NS	NS
CV[‡]	1.28	1.18	0.67	2.58

[†] LSD = least significant difference.
[‡] CV = coefficient of variation.

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

Infestation density	Bloom	Milk	Soft dough	Hard dough
(ft^2)	(%)			
0	55.88	57.52	54.82	52.96
1.37	55.91	58.06	53.97	51.19
2.75	55.86	56.37	55.11	52.06
5.49	55.32	56.20	53.87	51.34
$LSD_{0.10}$†	NS	NS	NS	NS
CV‡	2.62	2.82	2.25	3.43

† LSD = least significant difference.
‡ CV = coefficient of variation.

Table 7. Average values for selected parameters by rice stink bug infestation level across rice growth stages in 2016.

Rice stink bug infestation density	Damaged kernels	Rice stink bug damaged kernels	Grain yield	Blank kernels	Total milled rice yield	Whole kernel milled rice yield
(ft^2)	(%)		(bu/acre)	(%)		
0	3.12 c†	0.85 d	157.10	24.09	70.14	55.29
1.37	3.66 b	1.15 c	155.90	25.69	70.65	55.02
2.75	3.91 ab	1.54 b	158.69	27.35	70.21	55.04
5.49	4.20 a	1.81 a	151.94	26.85	69.71	54.19
$LSD_{0.10}$‡	0.44	0.24	NS	NS	NS	NS
CV§	19.58	30.12	6.48	31.47	1.50	3.07

† Means followed by the same letter within a column are not significantly different (P < 0.10).
‡ LSD = least significant difference.
§ CV = coefficient of variation.

Potential Exposure of Honey Bees to Neonicotinoid Insecticides in Rice

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Abstract

Insecticide seed treatments and foliar clothianidin applications were evaluated in 2015 and 2016 for expression in the flag leaf and floral parts of rice, as well as grain in 2016. Data analysis of samples indicated that insecticide seed treatments applied at planting and foliar applications made at pre-flood and post-flood were expressed at very low levels or were non-existent 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 (containing thiamethoxam) and NipsIt INSIDE® (containing clothianidin) are important for control of rice water weevil and grape colaspis. 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.

Procedures

Objective 1 – Measuring Levels of Neonicotinoid Insecticides in Rice Plants

Experiments were conducted at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center, Stuttgart, Ark. The cultivar in these

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studies was CL152, which was drill-seeded on 6 May 2015 and 6 May 2016, and grown according to standard agronomic practices for Arkansas. Plots were 180 × 63 inches on 7-inch drill spacing in a randomized complete block design with four replications. The treatments included: an untreated check, thiamethoxam as CruiserMaxx Rice seed treatment (7 oz/cwt); clothianidin as pre-flood Belay foliar (4.5 oz/acre); clothianidin as post-flood Belay foliar (4.5 oz/acre); and clothianidin as NipsIt INSIDE seed treatment (1.92 oz/acre). Pre-flood foliar applications were made 10 June 2015 and 8 June 2016, and post-flood applications were made 18 June 2015 and 16 June 2016.

Flag leaf and panicle samples were taken 5 August 2015 at 91 days after planting, 56 days after pre-flood foliar application, and 48 days after post-flood foliar treatment; and 2 August 2016 at 88 days after planting, 55 days after pre-flood foliar application, and 47 days after post-flood foliar treatment. Additionally in 2016, grain samples were taken on 26 September. Standard laboratory practices were conducted to assure 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. Panicles from each plot were removed, placed in a paper bag, stored on ice in a cooler, and brought to the laboratory for processing. 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. A sample size of 50 panicles was removed to ensure enough tissue for testing. From 30 panicles, 15 florets were removed, placed in a labeled conical tube, and weighed to ensure 3 g (0.106 oz) of tissue were present. If the sample weighed less than 3 g (0.106 oz), more florets were removed from the remaining panicles and the sample was weighed again. 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. Once processed, all samples were placed in a freezer until shipped.

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

In late-September 2015, 5 flowering rice fields in Arkansas County and 5 in Jefferson County were monitored for the presence of honey bees. Observations were made between the hours of 8:30 A.M. and 11:00 A.M. by traveling at least 5 transects of 300 ft sections, slowly walking and looking for honey bees visiting rice panicles. Similarly in 2016, from late-July through September, fifteen flowering rice fields in Arkansas County were monitored for the presence of honey bees; however, observations were made between the hours of 10:00 A.M. and 12:00 P.M. and 1:30 P.M. and 3:30 P.M. by traveling at least 4 transects of 300 ft sections. All observations were recorded as well as the location, stage of rice, and crops surrounding each field (Tables 1 and 2). 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

In 2015 flag leaf samples, CruiserMaxx Rice indicated a low level of thiamethoxam detection at 7.93 ppb, while NipsIt INSIDE and both Belay foliar applications had no detection of clothianidin (Table 3). A similar trend was observed for pollen with an even lower level of thiamethoxam found in florets and pollen with 2.23 ppb resulting from CruiserMaxx rice seed treatment. All other treatments had no detection of clothianidin in florets and pollen. In 2016, similar results were found with CruiserMaxx Rice thiamethoxam having 7.65 ppb thiamethoxam in the flag leaf and none detected in the pollen or the grain. No clothianidin was detected in florets and pollen from NipsIt INSIDE or Belay treatments in 2016. 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

In 2015, a total of 57 transects were made. In those transects, only one bee was observed (Table 4). In 2016, a total of 157 transects were made. In those transects, two bees were observed (Table 5). The crops surrounding each field had no impact on the appearance of bees in rice fields, and there was no difference in bee population based on time of day. Rice, like most of our major row crops, is 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 (Taillon et al., 2015). 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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Table 1. Field location of bee observations and surrounding crops or vegetation, 2015.

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

Table 2. Field location of bee observations and surrounding crops or vegetation, 2016.

Field	Field location	North of field	South of field	East of field	West of field
1	Arkansas	tree line	soybeans	soybeans and tree line	soybeans
2	Arkansas	soybeans	soybeans	rice	soybeans
3	Arkansas	rice	soybeans	rice	soybeans
4	Arkansas	soybeans	rice	soybeans	soybeans
5	Arkansas	rice	tree line	rice	tree line
6	Arkansas	corn	soybeans and rice	soybeans	pasture
7	Arkansas	rice	rice	tree line	soybeans
8	Arkansas	soybeans and rice	rice	reservoir	soybeans
9	Arkansas	tree line	soybeans	tree line	rice
10	Arkansas	soybeans	soybeans	rice	corn
11	Arkansas	flowering rice	soybeans	flowering rice	cut rice
12	Arkansas	soybeans	flowering rice	flowering rice	cut rice
13	Arkansas	rice	soybeans	rice	rice
14	Arkansas	rice	soybeans	soybeans	rice
15	Arkansas	soybeans	rice	soybeans	rice

Table 3. Levels of neonicotinoid insecticides (ppb) in the flag leaf and florets (2015 and 2016) and grain (2016) of rice from plots treated with thiamethoxam and clothianidin insecticide seed treatments at planting and clothianidin foliar applications made pre-flood or post-flood on rice at bloom.

	Neonicotinoid residues in rice				
	2015		2016		
Treatment	Pollen	Flag leaf	Pollen	Flag leaf	Grain
	(ppb)				
UTC	0 b[†]	0 b	0 a	0 b	0 a
Cruiser Maxx Rice 7 oz/cwt	2.23 a	7.93 a	0 a	7.65 a	0 a
Nipsit Inside 1.92 oz/cwt	0 b	0 b	0 a	0 b	0 a
Belay post-flood 4.5 oz/acre	0 b	0 b	0 a	0 b	0 a
Belay pre-flood 4.5 oz/acre	0 b	0 b	0 a	0 b	0 a

† Means followed by the same letter in a column do not significantly differ at least significant difference *P* = 0.05.

Table 4. 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) in 2015.

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

Table 5. The number of bees observed in flowering rice fields at different times of the day at 300 ft transects across the field in Arkansas County (observations = 157) in 2016.

				Number of bees in transect					
Field	Growth stage	Date	Time	1	2	3	4	5	6
1	Flowering	7/20	10:15 A.M.	0	0	0	0	0	0
1	Flowering	7/20	2:15 P.M.	0	0	0	0	0	-
2	Late Flowering	7/20	10:40 A.M.	0	0	0	0	0	0
2	Late Flowering	7/20	2:40 P.M.	0	0	0	0	0	-
3	Flowering	7/20	11:15 A.M.	0	0	0	0	0	0
3	Flowering	7/20	3:00 P.M.	0	0	0	0	0	-
4	Flowering	7/27	10:30 A.M.	0	0	0	0	0	-
5	Flowering	7/27	10:50 A.M.	1	0	0	0	-	-
6	Late Flowering	8/4	9:50 A.M.	0	0	0	0	-	-
6	Flowering	8/4	2:30 P.M.	0	0	0	0	-	-
7	Flowering	8/4	10:40 A.M.	0	0	0	0	-	-
7	Flowering	8/4	2:10 P.M.	0	0	0	0	0	-
8	Flowering	8/4	10:55 A.M.	0	0	0	0	0	-
8	Flowering	8/4	1:50 P.M.	0	0	0	0	-	-
9	Flowering	8/5	10:00 A.M.	0	0	0	0	-	-
9	Flowering	8/5	1:40 P.M.	0	0	0	0	-	-
10	Flowering	8/5	10:30 A.M.	0	0	0	0	0	0
10	Flowering	8/5	2:00 P.M.	0	0	0	0	0	0
11	Ratoon/Flowering	9/9	10:00 A.M.	0	0	0	0	0	0
11	Ratoon/Flowering	9/9	1:45 P.M.	0	0	0	0	0	0
12	Ratoon/Flowering	9/9	10:20 A.M.	0	0	0	0	0	0
12	Ratoon/Flowering	9/9	2:15 P.M.	0	0	0	0	0	0
13	Ratoon/Flowering	9/12	11:00 A.M.	0	0	0	0	0	0
13	Ratoon/Flowering	9/12	2:30 P.M.	0	0	0	0	0	0
14	Ratoon/Flowering	9/12	11:20 A.M.	0	0	0	0	0	1
14	Ratoon/Flowering	9/12	2:50 P.M.	0	0	0	0	0	0
15	Ratoon/Flowering	9/12	11:40 A.M.	0	0	0	0	0	0
15	Ratoon/Flowering	9/12	3:20 P.M.	0	0	0	0	0	0

Evaluation of Insecticide Seed Treatment Combinations for Control of Rice Water Weevil, *Lissorhoptrus oryzophilus*

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Abstract

Combinations of insecticide seed treatments were evaluated on conventional and hybrid cultivars to determine efficacy against rice water weevils, grape colaspis, and potentially other insects that feed on rice. No detrimental effects were observed for control of rice water weevil. Yields were taken but no significant differences were observed.

Introduction

Controlling rice insect pest is an integral part of rice production today and can often mean the difference in maintaining profitability for growers in Arkansas. Rice water weevil (RWW) and grape colaspis (GC) are both major pests in Arkansas rice. Damage to the rooting system by these pests can cause the plant to yellow and become stunted and, in many cases, can cause significant stand reduction and subsequently yield (Lorenz and Hardke, 2013). Thin stands caused by GC often result in increased rice water weevil (RWW) infestations which are attracted to areas in the field with a thin stand. Armyworms and rice billbug are minor pests that occasionally cause noticeable damage to rice, require action from producers, and in recent years appear to be an increasing problem. Armyworms feed on leaves and stems and may consume the entire above-ground rice seedling (Lorenz and Hardke, 2013). The growing point is usually not damaged and seedlings normally recover; however, crop maturity can be delayed. Billbug-injured plants turn brown and die. Adults are known to feed on the rice plant stem and the leaf whorl. Rows of oblong holes in expanded leaves are evidence that feeding has occurred. Larval feeding inside the root crown and lower stem gener-

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ally causes the plant to die. The main symptom that a stem is infested with a billbug larva is a whitehead (totally blank panicle) similar to the whiteheads caused by stem borers. Billbug larvae cannot survive flooded conditions, even when inside the plant stem. Rice billbug eggs are laid in the soil or near the base of the plant. Once the eggs hatch, larvae will feed on the inner tissue of the stem 2 inches above and below the soil surface. Billbug damage is mostly found on levees since they cannot survive flooded conditions. However with increasing acreage of "row rice", the potential problems with this pest may occur.

While neonicotinoid seed treatments such as thiamethoxam (Cruiser) and clothianidin (NipSit) are very effective for control of GC they do not provide the level of control that rynaxapyr (Dermacor) does for RWW. Also, rynaxapyr does not control GC, but provides excellent control of armyworms which are not controlled by the neonicotinoid seed treatments. Therefore, the purpose of this study was to evaluate combinations of these insecticide seed treatments for control of rice water weevils, as a start to determining the value of insecticide seed treatments that would provide adequate control of these pests in Arkansas.

Procedures

Trials were located at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC), Stuttgart, Ark.; and the University of Arkansas System Division of Agriculture's Pine Tree Research Station (PTRS) near Colt, Ark., using both hybrid (XL753) and conventional (CL 151) rice cultivars. Plot design was a randomized complete block with 4 replications. Plots were 70 × 63 inches using 7-inch drill spacing using standard agronomic practices to maintain these plots. Seed treatments in the conventional trial included an experimental insecticide at 0.025 and 0.03 mg ai /seed; CruiserMaxx® Rice 0.034 mg ai/seed (thiamethoxam + fungicides premix); Dermacor® X-100 0.017 mg ai/seed (chlorantraniliprole); NipsIt 0.0162 mg ai/seed (clothianidin); Cruiser Maxx 0.034 mg ai/seed with experimental at rates of 0.015, 0.025, or 0.03 mg ai/seed; and CruiserMaxx 0.034 mg ai/seed with Vibrance 0.043 mg ai/seed; and an untreated check (UTC) with the base fungicide.

Seed treatments in the hybrid trial included: an experimental insecticide at 0.04 mg ai/seed; Nipsit 0.018 mg ai/seed; Dermacor® X-100 0.017 mg ai/seed; CruiserMaxx® Rice 0.034 mg ai/seed; NipsIt 0.018 mg ai/seed combined with the experimental at rates of 0.015, 0.025, or 0.03 mg ai/seed; Dermacor 0.017 mg ai/seed with the experimental at 0.03 mg ai/seed; CruiserMaxx 0.034 mg ai/seed with the experimental 0.03; NipsIt + Dermacor, and CruiserMaxx + Dermacor at the same rates as above and an untreated check (UTC) with fungicide.

All seed treatments, as well as the UTC included a fungicide package of Apron XL (Mefenoxam), Maxim 4 FS (Fludioxonil), and Dynasty 83 FS (Azoxystrobin).

Rice water weevil larvae were evaluated by taking 3 core samples per plot with a 4-inch core sampler, 21 days after permanent flood. Each core was washed with water to loosen soil and remove larvae from the roots into a 40-mesh sieve. The sieve was then immersed in a saturated salt solution to float the larvae for counting. All samples were evaluated at the University of Arkansas System Division of Agriculture's Lonoke Agricultural Extension and Research Center. Yield was taken and adjusted to 12% moisture. Data were processed using Agriculture Research Manager Version 9 (Gylling Data Management, Inc., Brookings, S.D.), Analysis of Variance, and Duncan's New Multiple Range Test ($P = 0.10$).

Results and Discussion

Results in the conventional cultivar indicated that all treatments reduced the number of RWW compared to the UTC at both locations (Figs. 1 and 2). Differences ranged from 68% to 99% control of RWW compared to the UTC at the RREC and 43% to 76% control compared to the UTC at the PTRS.

Similar results were observed in the hybrid cultivar with all treatments reducing RWW compared to the UTC at both locations (Figs. 3 and 4). Differences ranged from 65% to 91% control at Stuttgart and 38% to 69% control at Pine Tree.

Yields were taken at both locations; however, no differences were observed.

Significance of Findings

Although there were no significant improvements to seed treatments when combined with other seed treatments, we also did not see any negative effects from these combinations. Due to these findings, further studies will be conducted to evaluate control of other pests in rice.

Acknowledgments

The author would like to extend thanks to the rice farmers of Arkansas who provide support through the rice check-off program and the support of the University of Arkansas System Division of Agriculture, Syngenta Crop Protection, Valent USA Co., and DuPont Crop Protection.

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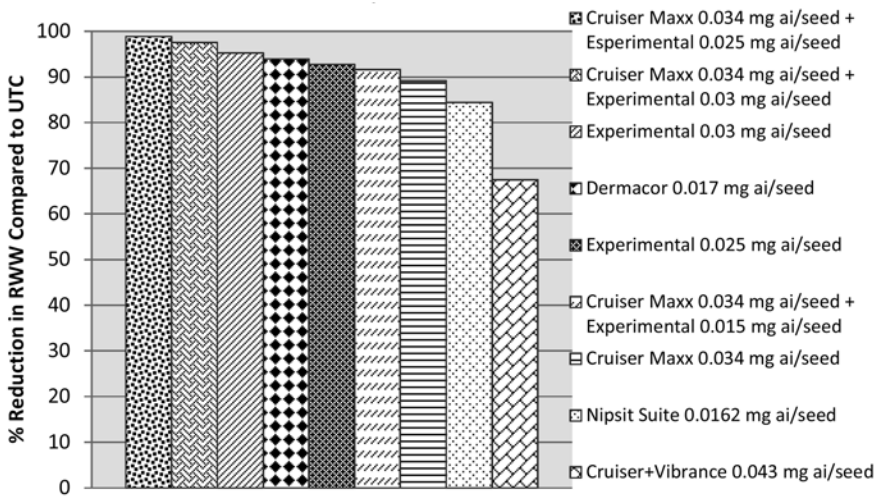

Fig. 1. Percent reduction in rice water weevils (RWW) compared to the untreated check (UTC) in conventional cultivar study at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center, Stuttgart, Ark., 2016.

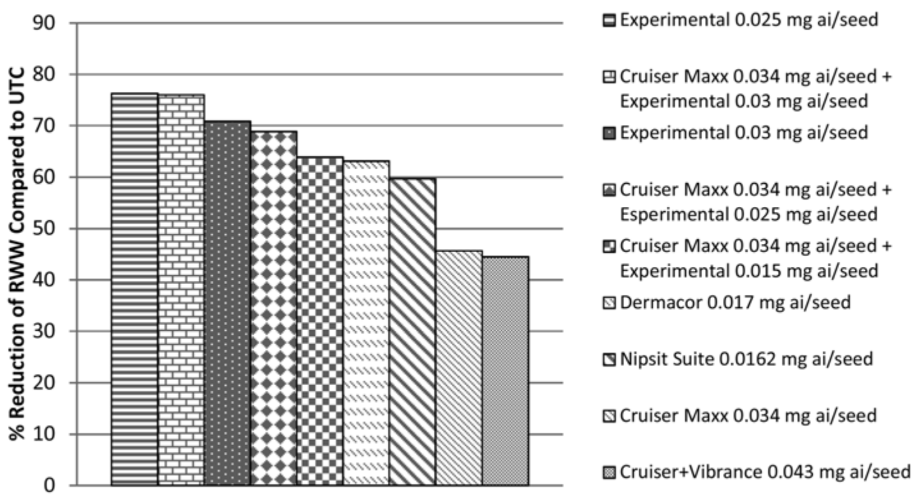

Fig. 2. Percent reduction in rice water weevils (RWW) compared to the untreated check (UTC) in conventional cultivar study at the University of Arkansas System Division of Agriculture's Pine Tree Research Station, Colt, Ark., 2016.

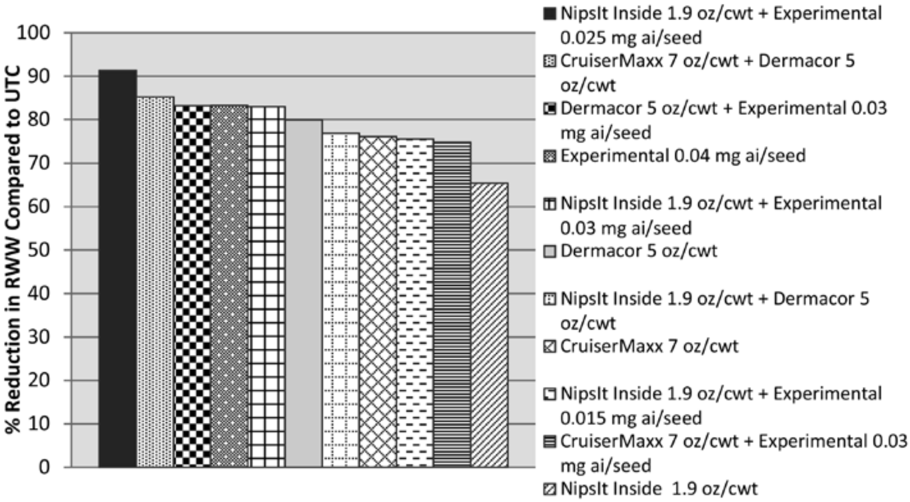

Fig. 3. Percent reduction in rice water weevils (RWW) compared to the untreated check (UTC) in hybrid cultivar study at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center, Stuttgart, Ark. 2016.

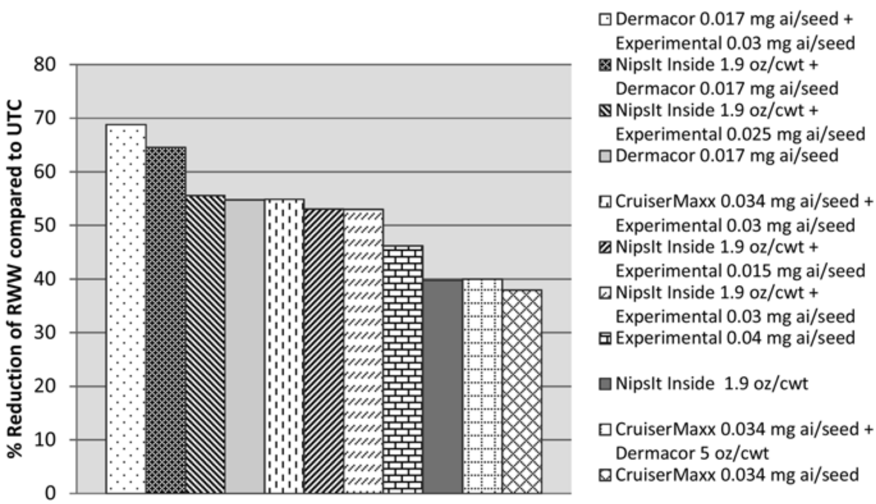

Fig. 4. Percent reduction in rice water weevils (RWW) compared to the untreated check (UTC) in hybrid cultivar study at the University of Arkansas System Division of Agriculture's Pine Tree Research Station, Colt, Ark., 2016.

Off-Target Drift of Glyphosate and Glufosinate on Late-Season Rice

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

Abstract

When grown in close proximity to other row-crop production systems, rice crops face the risk of potential damaging off-target herbicide drift scenarios. With increasing amounts of glufosinate (Liberty) and glyposhate (Roundup) being used in tolerant varieties of other crops, the likelihood for movement of those herbicides onto rice crops is high. Field research was conducted at the University of Arkansas System Division of Agriculture's Lonoke Extension Center, Lonoke, Ark., and the Rohwer Research Station, Rohwer, Ark., in 2016 to evaluate the effects on growth habits and yield of rice in response to simulated drift rates of glyphosate and glufosinate at varying growth stages. Results from the Lonoke location show that drift rates of glyphosate applied at early and late boot stages and glufosinate applied at the late boot stage reduced heading of the crop 45% to 65%, but did not result in any statistically different yield reductions. However, studies conducted at the Rohwer location determined that drift rates of glyphosate resulted in some stunting and reduced heading of the crop 70% to 100% when applied at the boot and 50% heading stages. This resulted in major yield losses. Also drift rates of glufosinate at this location resulted in 45%-70% necrosis of the rice when applied at the boot, 50% heading, and soft dough stages, which resulted in some minor yield reductions.

Introduction

Averaging around 1.3 million acres each year, Arkansas is known for being the largest rice-producing state in the U.S. In Arkansas, rice planting begins the last week of March and continues into the first weeks in June (Hardke et al., 2013). While this production timeline is used to maximize the potential of the rice production system, it also creates some challenges. Similar planting dates and growing stages between rice and various other crops grown in the state like corn, soybeans, and cotton re-

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sult in occurrences of one crop production system interfering with another. Because herbicide-resistant broadleaf weeds like palmer amaranth are becoming more and more common every season, more herbicide-resistant crop varieties such as RoundUp Ready and Liberty Link are being incorporated into production systems of other crops. This is a potential problem for non-resistant rice cultivars. The increase in usage of these systems increase the possibility of off-target drift onto rice crops. According to Kurtz and Street (2003), earlier rice planting dates will likely increase the possibility of rice injury caused by glyphosate because of increased glyphosate usage in adjacent crops. With the likelihood of drift scenarios increasing, amounts of potential damage should be evaluated. Ellis et al. (2003) determined that rates of glyphosate reduced yield 99% and 67% when applied early-post-emergence and 54% and 29% when applied late-post-emergence. They also saw yield reductions from glufosinate of 30% when applied late. The purpose of this research was to determine the effects drift scenarios of glyphosate and glufosinate occurring at varying growth stages had on the growth habits and yield of rice.

Procedures

Two studies were conducted in Arkansas in 2016 to determine the effects of drift rates of glyphosate and glufosinate on growth habits and yield of rice. One study was conducted at the the University of Arkansas System Division of Agriculture's Lonoke Extension Center, Lonoke, Ark., on a silt loam soil planted in the CL151 rice variety on 18 May 2016. Treatments were applied using a CO_2-pressurized backpack sprayer, calibrated to deliver 15 gal/acre. Treatments of glyphosate (0.113 lb ai/acre) and glufosinate (0.053 lb ai/acre) were applied at early boot, late boot, heading, milk, and soft dough crop stages. The second study was conducted the University of Arkansas System Division of Agriculture's Rohwer Research Station, Rohwer, Ark., on a Sharkey clay soil planted in the CL111 variety on 18 April 2016. Treatments there were applied using a Mudmaster sprayer equipped with a compressed air powered multi-boom, calibrated to deliver 12 gal/acre. Treatments of glyphosate (0.113 lb ai/acre) and glufosinate (0.053 lb ai/acre) were applied at boot, 50% heading, soft dough, hard dough, and draining crop stages. At both locations, evaluations were taken of crop heading reductions and crop injury on a scale from 0 to 100%, where 0 equals no head reduction or crop injury and 100 equals complete head reduction or crop injury. The rice was harvested and yields recorded at maturity. Data were subjected to analysis of variation and means were separated using Fisher's protected least significant difference ($P = 0.05$).

Results And Disscussion

At the Lonoke location, treatments of glyphosate applied at early and late boot stages delayed heading by 61% and 66% when evaluated at 15 days after the first application (DAA) (Table 1). Treatments of glufosinate applied at the early boot also resulted in delayed heading of 45% at 15 DAA. Very little necrotic crop injury was observed from treatments of glyphosate at any stage, while treatments of glufosinate applied at the heading, milk, and soft dough stages resulted in necrosis of the crop ranging from 20% to 26% when evaluated 38 DAA. Yield reductions were moderate and only statistically different when glyphosate was applied at the early boot stage (16% reduction) and when glufosinate was applied at the late boot and soft dough stages (14% and 24% reductions, respectively).

At the Rohwer location, evaluations made at 3 days after the draining application resulted in crop stunting of 40% and 18% from glyphosate applied at boot and 50% heading stages, respectively (Table 2). Levels of necrosis were also observed ranging from 34% to 71% after applications of glufosinate were made at the boot, 50% heading, and soft dough crop stages. The most detrimental damage from these treatments however was the reduction in heading. Heading reductions resulted from treatments of glyphosate applied at boot and 50% heading stages (99% and 66%, respectively) and glufosinate applied at boot, 50% heading, and soft dough stages (ranging from 31% to 61% reductions). Yields followed a similar pattern with rice receiving an application of glyphosate at the boot stage yielding nothing in comparison to the untreated check and rice receiving an application of glyphosate at the 50% heading stage yielding 44% in comparison to the untreated check.

Significance of Findings

At both locations, drift rates of both glyphosate and glufosinate at certain crop stages proved to have negative effects on rice plants. Treatments of glyphosate at multiple crop stages resulted in some noticeable crop stunting and reduced heading by 45% to 100% which resulted in yield losses. Drift treatments of glufosinate resulted in noticeable amounts of necrosis of the crop ranging from 45% to 75% in the worst cases and also reduced heading, but resulted in only minor yield reductions. In conclusion, these results show the following drift scenarios could result in crop damage and potential yield reductions: glyphosate at the early boot, boot, and 50% heading stage and glufosinate at the boot, 50% heading, and soft dough stages (mainly injury at the soft dough stage).

Acknowledgments

Sincere gratitude is extended to the Arkansas Rice Research and Promotion Board and the University of Arkansas System Division of Agriculture for supporting and funding this project.

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Kurtz, M.E. and Street, J.E. 2003. Response of rice (*Oryza sativa*) to glyphosate applied to simulate drift. Weed Technol. 17:234-238.

Table 1. Glyphosate and glufosinate rates, timing, percent injury, delayed heading and yield as percent of the untreated check at Lonoke, Ark.

Treatment	Rate[a]	Timing	Injury	Delayed heading	Yield
	(lb ai/acre)		------------ (%)	------------	(% of UTC[b])
UTC	----	----	0	0	----
Glyphosate	0.113	Early Boot	8	66	84
Glyphosate	0.113	Late Boot	5	61	94
Glyphosate	0.113	Heading	5	0	97
Glyphosate	0.113	Milk	6	0	89
Glyphosate	0.113	Soft Dough	12	0	102
Glufosinate	0.053	Early Boot	9	45	96
Glufosinate	0.053	Late Boot	9	0	86
Glufosinate	0.053	Heading	20	0	90
Glufosinate	0.053	Milk	26	0	92
Glufosinate	0.053	Soft Dough	23	0	76
LSD (0.05)			8	30	18

[a] lb ai/acre = pound active ingredient per acre.
[b] UTC = untreated check.

Table 2. Glyphosate and glufosinate rates, timing, percent stunting and necrosis, delayed heading, and yield as percent of the untreated check at Rohwer, Ark.

Treatment	Rate[a]	Timing	Crop injury: Stunting	Crop injury: Necrosis	Heading	Yield
	(lb ai/acre)		-------------------	(%)	-------------------	(% of UTC[b])
UTC	----	----	0	0	100	----
Glyphosate	0.113	Boot	40	5	0	0
Glyphosate	0.113	50% Heading	18	10	34	44
Glyphosate	0.113	Soft Dough	0	0	94	98
Glyphosate	0.113	Hard Dough	0	9	99	82
Glyphosate	0.113	Draining	0	0	96	109
Glufosinate	0.053	Boot	20	34	39	77
Glufosinate	0.053	50% Heading	0	46	50	81
Glufosinate	0.053	Soft Dough	0	71	69	102
Glufosinate	0.053	Hard Dough	0	20	99	98
Glufosinate	0.053	Draining	0	8	99	115
LSD			10	24	25	26

[a] lb ai/acre = pound active ingredient per acre.
[b] UTC = untreated check.

Off-Target Drift of Paraquat and Sodium Chlorate on Late-Season Rice

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

Abstract

Growing two different crops in the same general area can lead to difficulties when it comes to controlling drift of herbicides. When growing rice in the same area as other crop programs such as soybeans or cotton, there is a risk that some rice-damaging herbicides could find their way to the crop. Late-season rice has a particular high chance of a drift scenario because of defoliants and harvest aids being sprayed on other nearby crops. Field research was conducted at the University of Arkansas System Division of Agriculture's Lonoke Extension Center, Lonoke, Ark., and the Rohwer Research Station, Rohwer, Ark., in 2016 to evaluate the effects on growth habits and yields of rice in response to simulated drift rates of paraquat and sodium chlorate when applied at multiple crop growth stages. Results from the Lonoke location show severe necrosis (up to 71%) of the crop following an application of paraquat at multiple stages, which resulted in yield reductions of greater than 90% when applied at early boot and late boot stages. Sodium chlorate had little to no impact on crop growth or yield. At the Rohwer location, greater than 75% necrosis was observed following an application of paraquat at the soft and hard dough stages, resulting in some yield reductions. Similar to the Lonoke location, very little crop injury was observed at the Rohwer location following applications of sodium chlorate, and statistically no yields were reduced.

Introduction

Each year about 1.3 million acres of rice is planted in Arkansas. Generally planting begins in late March and extends into the beginning weeks of June (Hardke et al., 2013). Because this planting timing coincides with other popular crop production systems in the state like soybeans, challenges to be faced later in the growing season are created. Harvest aids or herbicides used as harvest aids, like sodium chlorate and paraquat, have become an important tool when growing early-maturing varieties of soybeans

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(Boudreaux and Griffin, 2008). With these early-maturing varieties of soybeans being planted simultaneously with rice, harvest aids used later in the season for desiccation of those soybeans are likely to drift onto neighboring rice crops when they are not applied in the proper conditions or using the proper equipment. This drift would most likely occur in the later, maturity stages of rice growth. According to Kurtz and Street (2003), earlier rice planting dates will likely increase the possibility of rice injury. The purpose of this research was to determine the effects of drift scenarios of paraquat and sodium chlorate occurring at multiple crop growth stages on the growth habits and yield of rice.

Procedures

Two studies were conducted in 2016 to determine the effects of drift rates of paraquat and sodium chlorate on growth habits and yield of rice. Once study was conducted at the University of Arkansas System Division of Agriculture's Lonoke Experiment Station, Lonoke, Ark. Trials were planted on a silt loam soil with the CL151 variety on 18 May 2016 . Applications were made using a CO_2-pressurized backpack sprayer calibrated to deliver 15 gal/acre. Treatments of paraquat were applied at 0.0625 lb ai/acre and treatments of sodium chlorate were applied at 0.6 lb ai/acre. Both treatments were applied at the early boot, late boot, and heading stages. Another study was conducted at the University of Arkansas System Division of Agriculture's Rohwer Research Station, Rohwer, Ark., were the CL111 variety was planted 18 April 2016 on a Sharkey clay soil. Treatments were applied using a Mudmaster sprayer equipped with a compressed air powered multi-boom, calibrated to deliver 12 gal/acre. Treatments of paraquat and sodium chlorate were applied at 0.0625 lb ai/acre and 0.6 lb ai/acre, respectively, at the soft dough, hard dough, and draining crop growth stages. Data was taken at both locations for crop injury ranging from 0 to 100%, where 0 equals no injury and 100 equals complete crop injury. The rice was harvested and yields recorded at maturity. Data were subjected to analysis of variation and means were separated using Fisher's protected least significant difference ($P = 0.05$).

Results and Disscussion

From the Lonoke location, data indicate that drift amounts of paraquat when applied at all three stages (early boot, late boot, and heading) result in necrosis injury of the crop ranging from 40-71% when evaluated 38 days after the early boot application (DAA), the greatest (71%) when the application was made at the heading stage (Table 1). Yields were significantly reduced when rice received a treatment of paraquat at the early boot and late boot stages where yields were reduced 90% compared to the yield of the untreated check. Rice receiving an application of paraquat at the heading stage yielded 64% compared to the untreated check. Very little injury was observed following treatments of sodium chlorate at all three stages and there were no yield reductions.

Data from Rohwer also indicate substantial necrosis injury of 91% and 79% following paraquat treatments applied at the soft dough and hard dough stages, respectively

(Table 2). Some minor stunting was also observed following an application of paraquat at the soft dough stage of 20%. The only treatment that resulted in a statistically reduced yield was when paraquat was applied at the soft dough crop stage, where plots yielded 55% in comparison to the untreated check. Similar to the Lonoke location, treatments of sodium chlorate resulted in very little noticeable crop injury and the yields were not statistically affected.

Significance of Findings

At both locations, applications of drift rates of paraquat resulted in substantial crop necrosis ranging from 14% to 91%. When applied at the earlier maturity timings such as early boot, late boot, heading, and soft dough stages, yields were affected 45% to 96%. When applied at later maturity timings such as hard dough and draining, necrosis of the crop was still observed but little yield reductions occurred. Evaluations made following applications of drift rates of sodium chlorate resulted in very little crop injury and no yield reductions when applied at any crop stage. In conclusion, these studies show that a drift scenario of paraquat would result in noticeable crop injury and could reduce yields if it occurs at the early boot, late boot, heading, and soft dough stages. Also, in the event of sodium chlorate drift, little crop injury should be expected and yields should not be reduced.

Acknowledgments

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

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Kurtz, M.E. and J.E. Street. 2003. Response of Rice (*Oryza sativa*) to glyphosate applied to simulate drift. Weed Technol. 17:234-238.

Table 1. Sodium chlorate and paraquat rates, timing, percent injury, and yield as percent of the untreated check at Lonoke, Ark.

Treatment	Rate[a]	Timing	Crop injury	Yield
	(lb ai/acre)		(% necrosis)	(% of UTC[b])
UTC	----	----	0	----
Sodium chlorate	0.6	early boot	21	104
Sodium chlorate	0.6	late boot	6	109
Sodium chlorate	0.6	heading	9	100
Paraquat	0.0625	early boot	40	8
Paraquat	0.0625	late boot	48	4
Paraquat	0.0625	heading	71	64
LSD			18	18

[a] lb ai/acre = pound active ingredient per acre.
[b] UTC = untreated check.

Table 2. Sodium chlorate and paraquat rates, timing, percent stunting and necrosis, and yield as percent of the untreated check at Rohwer, Ark.

			% Crop injury		
Treatment	Rate[a]	Timing	Stunting	Necrosis	Yield
	(lb ai/acre)		------------- (%) -------------		(% of UTC[b])
UTCb	----	----	0	0	----
Sodium chlorate	0.6	soft dough	14	0	77
Sodium chlorate	0.6	hard dough	3	6	92
Sodium chlorate	0.6	draining	8.8	7.5	89
Paraquat	0.0625	soft dough	20	91	55
Paraquat	0.0625	hard dough	9	79	91
Paraquat	0.0625	draining	6	14	82
LSD			24	10	32

[a] lb ai/acre = pound active ingredient per acre.
[b] UTC = untreated check.

Influence of Formulation and Rate on Rice Tolerance to Early-Season Applications of Acetochlor

M.E. Fogleman[1], J.K. Norsworthy[1], J.A. Godwin Jr.[1], M.L. Young[1], and R.C. Scott[2]

Abstract

Repeated use of the same herbicide sites of action (SOA) has left growers with few effective management strategies for controlling herbicide-resistant weeds in mid-South rice. By targeting alternative SOA [Weed Science Society of America (WSSA) Group 15], very long-chain fatty acid-inhibiting herbicides such as acetochlor may provide control of problematic species. A field experiment was conducted in summer 2016 at the University of Arkansas System Division of Agriculture's Pine Tree Research Station (PTRS) near Colt, Ark., and at the University of Arkansas Pine Bluff (UAPB) farm near Lonoke, Ark., to determine the effects of acetochlor formulation and rate on rice tolerance. The experiment was arranged as a three-factor, randomized complete block design with factors being A) formulation (micro-encapsulated as Warrant and emulsifiable concentrate as Harness); B) application rates (1X and 2X); and C) application timing of pre-emergence (PRE), delayed pre-emergence (DPRE), and early post-emergence (EPOST). Overall, rice exhibited a higher tolerance to applications of Warrant than to Harness, likely due to formulation differences between the two. At both locations, applications at the PRE or DPRE timing were most injurious. Rainfall prior to application at the PTRS location resulted in higher initial injury; however, a lack of rainfall resulted in delayed, but more severe injury at Lonoke. There were significant differences in yield response between the locations; however, the same general trend was observed. Minimal crop injury (< 5%) was observed across all Warrant treatments at 4 wk after flood when applied at the EPOST timing, suggesting that applications should be delayed until this timing to reduce stand loss and rice injury.

Introduction

Weed control is arguably one of the most difficult and most important factors in growing a quality rice crop. Barnyardgrass (*Echinochloa crus-galli*) is a notoriously problematic weed in rice fields across North America and is the most important weed

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in Arkansas rice production today, evolving resistance to several commonly used rice herbicides including clomazone, propanil, and imazethapyr (Lovelace, 2003; Norsworthy et al., 2009; Riar et al., 2013). Warrant and Harness are two Weed Science Society of America (WSSA) Group 15 very-long chain fatty acid (VLCFA)-inhibiting herbicides currently labeled in cotton, corn, grain sorghum and soybean. In a study by Cahoon et al. (2015), acetochlor provided 84%, 91%, and 100% control of Palmer amaranth (*Amaranthus palmeri*), large crabgrass (*Digitaria sanguinalis*), and goosegrass (*Eleusine indica*), respectively. This study suggests that Warrant is capable of controlling problematic weeds commonly found in the mid-South. Because Group 15 herbicides have a low risk for developing resistance and offer weed control via an alternative mode of action, acetochlor has a potential fit in Arkansas rice production (Heap, 2016). The objective of this study was to determine the influence of acetochlor formulation and rate on rice tolerance to pre-emergence (PRE), delayed pre-emergence (DPRE), and early post-emergence (EPOST) application timings.

Procedures

A field experiment was conducted in the summer of 2016 at the University of Arkansas System Division of Agriculture's Pine Tree Research Station (PTRS) near Colt, Arkansas and at the University of Arkansas Pine Bluff Farm (UAPB) near Lonoke, Arkansas to determine rice tolerance to early-season applications of acetochlor. Clearfield 111 rice was drill-seeded at 22 seed/ft of row with 7-in. spacing into plots measuring 6 ft × 17 ft. The experimental design was a randomized complete block with a three-factor factorial treatment structure and four replications. The first factor consisted of two formulations of acetochlor: micro-encapsulated (ME) as Warrant and emulsifiable concentrate (EC) as Harness. The second factor consisted of two herbicide rates: Warrant at 2.5 (1X) and 5 pt/acre (2X), and Harness at 16 (1X) and 32 fl oz/acre (2X). The third factor consisted of three application timings: PRE, DPRE, and EPOST. Delayed pre-emergence applications were made at 5 days after planting (DAP) and EPOST applications were made at the 1- to 2-lf rice stage.

All applications were made using a CO_2-pressurized backpack sprayer calibrated to deliver 15 gal/acre using AIXR 100015 nozzles. Visual ratings of crop injury were estimated at 2, 4, 6, and 8 wk after treatment (WAT) on a scale of 0% to 100%, with 0% indicating no injury and 100% indicating complete crop death. Rough rice grain was harvested at crop maturity using a small-plot combine. Data were subjected to analysis of variance in JMP Pro 12 (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

A significant interaction between formulation, rate, and application timing was observed for injury rated 2 WAT and 4 weeks after flood (WAF) at both locations. In general, crop injury decreased from 2 WAT to 4 WAF at PTRS; however, the opposite was true at UAPB, likely due to rainfall differences between locations and across timings (Fig. 1). Rice showed increased tolerance to the ME formulation of acetochlor (Warrant) than the EC formulation (Harness) across all application timings, although PRE and DPRE timings were most injurious regardless of formulation (Figs. 2 and 3). The gradual release of acetochlor in Warrant and the immediate and total release of acetochlor in Harness likely explain the differences in crop injury between the two formulations. Applications of Harness often resulted in unacceptable crop injury at PRE and DPRE application timings, particularly following excessive rainfall events. Overall, grain yields at PTRS were higher than grain yields at UAPB, though trends in the response were similar (Fig. 4). Furthermore, minimal differences (<30 bu/acre) in yield among Warrant treatments were observed, while differences varied widely among Harness treatments at both locations.

Significance of Findings

The results of this study indicate that rice is most tolerant to acetochlor when applied EPOST as Warrant. Severity of injury may depend upon timing of herbicide activation (via rainfall, irrigation, tillage, etc.) where acetochlor was quickly activated by a rainfall event that occurred prior to application at PTRS but was delayed at UAPB. Although not currently labeled for use in rice, Warrant could potentially provide growers with an alternative site of action for controlling resistant rice weeds such as barnyardgrass without causing significant crop injury. Should future research prove the EPOST timing to be advantageous for weed control, the registration of Warrant for use in Arkansas rice would provide growers with another effective weed management tool.

Acknowledgments

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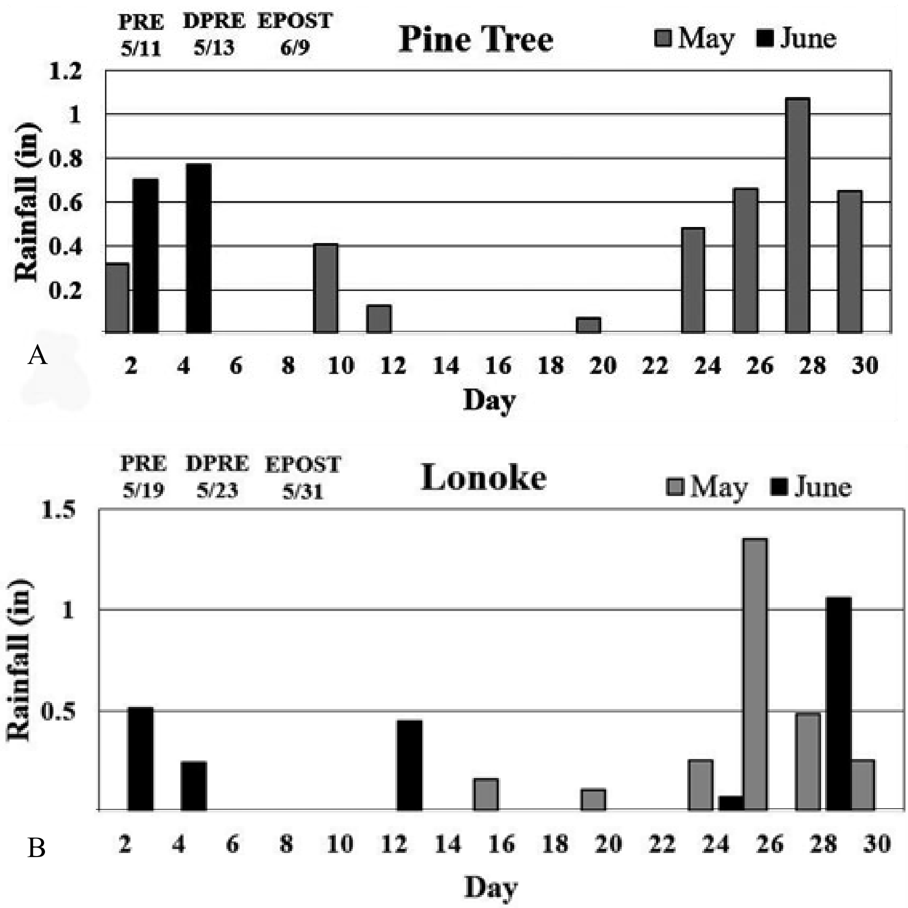

Fig. 1. Rainfall data for May and June of 2016 at (A) the University of Arkansas System Division of Agriculture's Pine Tree Research Station near Colt, Ark., and (B) the University of Arkansas at Pine Bluff Farm near Lonoke, Ark.

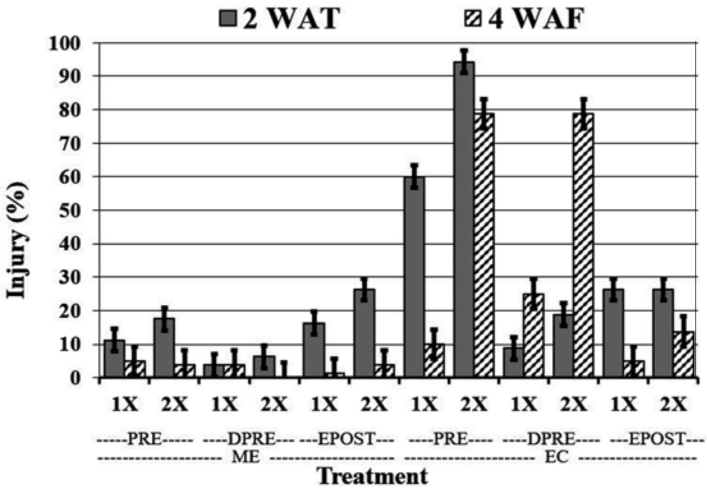

Fig. 2. Visual injury ratings (%) 2 weeks after treatment (WAT) and 4 weeks after flooding (WAF) at the University of Arkansas System Division of Agriculture's Pine Tree Research Station. Bars on each mean represent Fisher's protected least significant difference and allow for comparison among treatment means.

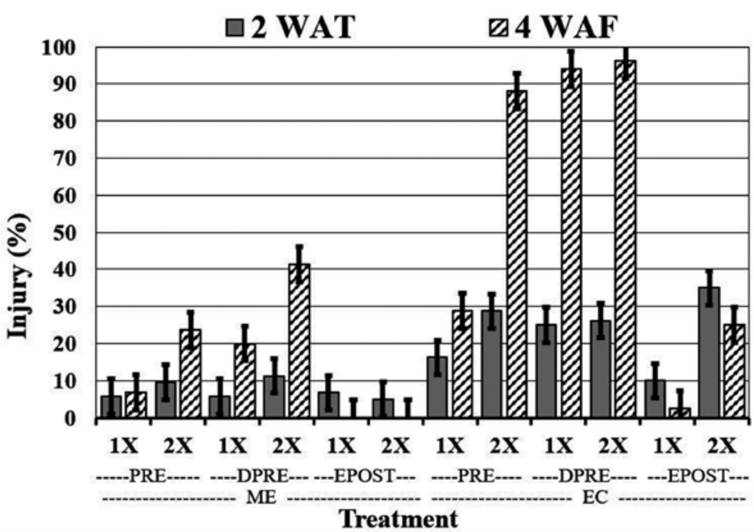

Fig. 3. Visual injury ratings (%) 2 weeks after treatment (WAT) and 4 weeks after flooding (WAF) at the University of Arkansas at Pine Bluff Farm. Bars on each mean represent Fisher's protected least significant difference and allow for comparison among treatment means. Abbreviations: PRE, pre-emergence; DPRE, delayed pre-emergence; EPOST, early post-emergence; ME, micro-encapsulated; EC, emulsifiable concentration.

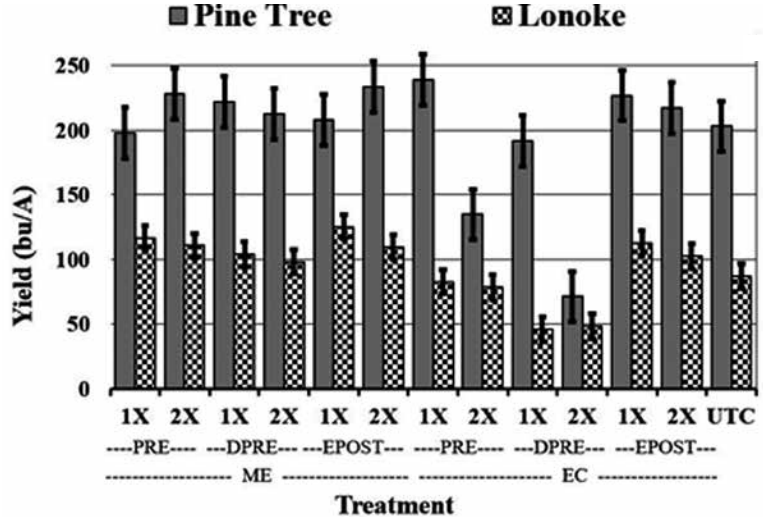

Fig. 4. Rough rice yield (bu/acre) as influenced by treatment, compared to an untreated control (UTC) at the University of Arkansas System Division of Agriculture's Pine Tree Research Station near Colt, Ark., and the University of Arkansas at Pine Bluff Farm near Lonoke, Ark. Bars on each mean represent Fisher's protected least significant difference and allow for comparison among treatment means within a location. Abbreviations: PRE, pre-emergence; DPRE, delayed pre-emergence; EPOST, early post-emergence; ME, micro-encapsulated; EC, emulsifiable concentration.

Evaluation of Post-Emergence Weed Control Programs Containing Pethoxamid in Rice

J.A. Godwin Jr.[1], J.K. Norsworthy[1], R.C. Scott[2], and M.L. Young[1]

Abstract

The evolution of herbicide resistance to problematic weed species in rice such as barnyardgrass [*Echinochloa crus-galli* (L.) Beauv.] and red rice (*Oryza sativa* var. *sylvatica* L.) is making chemical weed control extremely difficult. Currently, no very-long-chain fatty acid (VLCFA)-inhibiting herbicides are labeled for use in U.S. rice production. Pethoxamid is one such herbicide under development for use in rice and various row crops for control of annual grasses and small-seeded broadleaves. Field trials were conducted in 2015 and 2016 at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC), near Stuttgart, Ark., and in 2016 at the University of Arkansas at Pine Bluff Farm (UAPB) near Lonoke, Ark., and the University of Arkansas System Division of Agriculture's Pine Tree Research Station (PTRS), near Colt, Ark., to evaluate rice tolerance and weed control associated with pethoxamid-containing herbicide programs applied post-emergence (POST) in rice. Pethoxamid was applied at 0.375 and 0.50 lb ai/acre alone and in a program with clomazone, quinclorac, propanil, imazethapyr, and carfentrazone. Rice injury dissipated to less than 5% for all treatments by 4 weeks after permanent rice flooding (WAF) in the trial near Stuttgart. Late-season barnyardgrass control greater than 93% was seen in trials near Lonoke and Colt at 4 WAF for programs containing clomazone pre-emergence (PRE) followed by (fb) pethoxamid + quinclorac or imazethapyr at 3- to 4-lf rice. Due to the low levels of injury and adequate levels of barnyardgrass control associated with pethoxamid-containing herbicide programs, pethoxamid represents a unique herbicide site of action (SOA) with excellent potential in U.S. rice.

Introduction

Pethoxamid (FMC Corporation, Philadelphia, Pa.) is a very-long-chain fatty acid (VLCFA)-inhibiting herbicide, which belongs to the chloroacetamide family. Pethoxamid is currently under development in the U.S. for use in canola (*Brassica napus* L.),

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corn (*Zea mays* L.), cotton (*Gossypium hirsutum* L.), rice, soybean [*Glycine max* (L.) Merr.], and sunflower (*Helianthus annuus* L.). Currently, there are no VLCFA-inhibiting herbicides labeled for use in U.S. rice production; therefore, pethoxamid would present a unique site of action (SOA) to combat herbicide-resistant weeds in rice.

Barnyardgrass in Arkansas has been confirmed to have resistance to propanil, quinclorac, clomazone, and imazethapyr among several other acetolactate synthase (ALS)-inhibiting herbicides (Norsworthy et al., 2012a). The leading cause for the evolution of herbicide resistance is the over-reliance of any one herbicide SOA (Norsworthy et al., 2012b); therefore, pethoxamid could provide growers an additional SOA to alternate, apply sequentially, or tank mix in U.S. rice to control herbicide-resistant weeds.

Some preliminary research has been conducted on the use of pethoxamid in U.S. rice. Pethoxamid applied at 0.50 and 0.75 lb ai/acre delayed pre-emergence (DPRE), to spiking, or to 1- to 2-lf rice caused only 5% injury when averaged over all application timings 2 to 3 weeks after treatment, with no reduction in yield compared to the non-treated control on a silt loam soil (Godwin et al., 2016). Pethoxamid was also applied at 0.375 and 0.50 lb ai/acre alone and in combination with other rice herbicides including: clomazone, imazethapyr, pendimethalin, and quinclorac to spiking rice. No visible crop injury was observed and acceptable levels of barnyardgrass and Amazon sprangletop (*Leptichloa panicoides* J Presl.) control were attained. At 66 days after application, pethoxamid alone at 0.375 lb ai/acre provided 84% control of barnyardgrass and 91% control of Amazon sprangletop. Amazon sprangletop and barnyardgrass control >95% was obtained following pethoxamid at 0.50 lb ai/acre + imazethapyr at 0.063 lb ai/acre (Doherty et al., 2016). These results indicate that the highest levels of weed control are associated with the use of pethoxamid in combination with another effective rice herbicide rather than applied alone.

Since rice has displayed tolerance to pethoxamid, and barnyardgrass control has been obtained with pethoxamid-containing herbicide programs, it is believed that pethoxamid may provide a unique SOA for use in U.S. rice. The objective of this research was to assess pethoxamid applied alone and in a post-emergence (POST) program in rice. It was hypothesized that rice would tolerate pethoxamid applied alone and in combination with other rice herbicides applied POST, as well as provide acceptable barnyardgrass control.

Procedures

Field trials were conducted in 2015 and 2016 at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC), Stuttgart, Ark., for rice tolerance, and in 2016 at the University of Arkansas at Pine Bluff Farm (UAPB) near Lonoke, Ark., and the University of Arkansas System Division of Agriculture's Pine Tree Research Station (PTRS) near Colt, Ark., for weed control. The soil texture at each location was a silt loam. Imidazolinone-resistant Clearfield™ (BASF Corporation, Research Triangle Park, N.C.) inbred rice cultivars CL111 (RREC) and CL151 (PTRS and UAPB) were drill-seeded into 6 ft × 17 ft plots at a seeding rate of 22 seeds/ft of row on a 7-in. row width. Rice was planted on 5 May 2015 and 25 April 2016 at the RREC, 9 May 2016 at the PTRS, and 18 May 2016 at the UAPB farm.

The experiments were conducted as a randomized complete block design with four replications. Twelve herbicide treatments were evaluated along with a nontreated control. The treatments evaluated included pethoxamid applied alone at 0.375 and 0.50 lb ai/acre to 1-lf rice, pethoxamid at 0.375 and 0.50 lb ai/acre + clomazone (Command 3ME, FMC Corporation, Philadelphia, Pa.) at 0.30 lb ai/acre to 1-lf rice, and clomazone applied pre-emergence (PRE) at 0.30 lb ai/acre followed by (fb) pethoxamid at 0.375 lb ai/acre and 0.50 lb ai/acre in combination with quinclorac (Facet® L, BASF Corporation, Research Triangle Park, N.C.) at 0.375 lb ai/acre, propanil (Stam® M4, RiceCo USA, Fair Oaks, Calif.) at 4 lb ai/acre, imazethapyr (Newpath®, BASF Corporation, Research Triangle Park, N.C.) at 0.063 lb ai/acre, and carfentrazone (AIM EC, FMC Corporation, Philadelphia, Pa.) at 0.016 lb ai/acre to 3- to 4-lf rice (Table 1). A nonionic surfactant (NIS) was used at 0.25% v/v in combination with the pethoxamid + quinclorac, pethoxamid + imazethapyr, and pethoxamid + carfentrazone applications at 3- to 4-lf rice. All herbicides were applied with a CO_2-pressurized backpack sprayer through 110015 AIXR (TeeJet) nozzles calibrated to deliver 15 gal/acre using a three-nozzle boom at 20-inch nozzle spacing at 3 MPH.

Data collection at the RREC (tolerance trials) included visual assessment of crop injury (0-100%), with 0% being no injury and 100% being crop death, and rough rice yield in bushels per acre (bu/acre) were reported. Data collection at UAPB and PTRS included a visual assessment of barnyardgrass control (0-100%) compared to the nontreated control.

Data were analyzed using JMP Pro 12 (SAS Institute Inc. Cary, N.C.) using the MIXED procedure. Data were separated for site-year and analyzed using analysis of variance (ANOVA) with replication included as a random variable. The nontreated control was removed from the analysis for rice tolerance and barnyardgrass control. All means were separated using Fisher's protected least significant difference ($P = 0.05$).

Results and Discussion

At the RREC, 2 weeks after treatment (WAT) rice injury ratings were less than 10% for all treatments in both 2015 and 2016, except for pethoxamid at 0.50 lb ai/acre + clomazone to 1-lf rice (Table 1). Rice injury dissipated to less than 5% following all treatments by 4 weeks after flooding (WAF; data not shown). These findings correlate with previous research where pethoxamid applied DPRE and to spiking and 1- to 2-lf rice caused 5% injury 2 to 3 WAT when averaged over all application timings (Godwin et al., 2016).

Minimal reduction in yield as a function of herbicidal injury was observed following any treatment assessed at the RREC (Table 1). All treatments resulted in rice yields statistically greater than or equal to the nontreated control yields of 164 bu/acre in 2015 and 140 bu/acre in 2016. The low amount of visual injury or reduction in rice yield following any pethoxamid-containing treatment displays the tolerance of rice to pethoxamid applied POST.

Barnyardgrass control ≥97% was observed both 3 WAT and 4 WAF at PTRS following treatments that included clomazone PRE fb pethoxamid at both 0.375 and 0.50 lb ai/acre + quinclorac, propanil, imazethapyr, and carfentrazone (Table 2). At UAPB, barnyardgrass control was ≥ 93% at 3 WAT and 4 WAF following all treatments containing clomazone PRE fb pethoxamid (at either rate assessed) + quinclorac and imazethapyr (Table 2). Barnyardgrass populations at UAPB are assumed to be resistant to propanil; therefore, less control with propanil-containing programs would be expected.

Significance of Findings

Considering the minimal injury or reduction in yield associated with pethoxamid-containing treatments applied POST to rice, it is believed that pethoxamid can be used safely in rice at the timings assessed. Pethoxamid provided effective barnyardgrass control at PTRS both 3 WAT and 4 WAF when applied in a program with other rice herbicides. In general, at both the PTRS and UAPB locations, rice treated with pethoxamid in a herbicidal program compared to pethoxamid applied alone resulted in greater levels of barnyardgrass control. Hence, pethoxamid provides a unique and effective SOA to use in combination with other rice herbicides to combat herbicide-resistant weed species in rice, but it is not a stand-alone herbicide. Pethoxamid could be a useful in-season tool to help manage current resistant barnyardgrass populations.

Acknowledgments

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Table 1. Rice injury and rough rice yield 2 weeks after treatment (WAT) at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC) near Stuttgart, Ark., in 2015 and 2016.

Program no.	PRE† herbicide	POST† herbicide	POST† timing	Pethoxmid rate	Injury 2 WAT‡ 2015	Injury 2 WAT‡ 2016	Yield‡ 2015	Yield‡ 2016
				(lb ai/acre)	(%)	(%)	(bu/acre)	(bu/acre)
1	Nontreated						164 e-g	140 d-f
2		Pethoxamid	1-lf	0.375	1 c	7 bc	152 g	126 f
3		Pethoxamid	1-lf	0.50	3 bc	5 cd	194 a	136 d-f
4		Pethoxamid + clomazone	1-lf	0.375	8 ab	8 b	171 c-g	127 ef
5		Pethoxamid + clomazone	1-lf	0.50	13 a	11 a	169 d-g	144 c-f
6	Clomazone	Pethoxamid + quinclorac	3-4 lf	0.375	3 bc	1 e	189 a-d	164 ab
7	Clomazone	Pethoxamid + quinclorac	3-4 lf	0.50	2 c	3 de	180 a-e	145 c-d
8	Clomazone	Pethoxamid + propanil	3-4 lf	0.375	5 bc	2 de	185 a-d	173 a
9	Clomazone	Pethoxamid + propanil	3-4 lf	0.50	4 bc	3 de	174 b-f	158 a-c
10	Clomazone	Pethoxamid + imazethapyr	3-4 lf	0.375	1 c	3 de	153 fg	152 b-d
11	Clomazone	Pethoxamid + imazethapyr	3-4 lf	0.50	1 c	2 de	90 a-c	153 b-d
12	Clomazone	Pethoxamid + carfentrazone	3-4 lf	0.375	1 c	2 de	192 ab	165 ab
13	Clomazone	Pethoxamid + carfentrazone	3-4 lf	0.50	1 c	3 de	191 a-c	160 a-c
				P-value	0.0033	<0.0001	0.0001	<0.0001

† PRE = pre-emergence; POST = post-emergence.

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

Table 2. Barnyardgrass control 3 weeks after treatment (WAT) and 4 weeks after permanent flood (WAF) at the University of Arkansas at Pine Bluff Farm (UAPB) near Lonoke, Ark. and the Pine Tree Research Station (PTRS) near Colt, Ark.

Program no.	PRE† herbicide	POST† herbicide	POST† timing	Pethoxmid rate	Barnyardgrass control			
					3 WAT‡		4 WAF‡	
					PTRS	UAPB	PTRS	UAPB
				(g ai ha-1)	(%)			
1	Nontreated							
2		Pethoxamid	1-lf	420	94 c	84 d	81 d	71 c
3		Pethoxamid	1-lf	560	94 c	94 ab	88 c	90 a
4		Pethoxamid + clomazone	1-lf	420	97 a-c	91 a-c	90 c	91 a
5		Pethoxamid + clomazone	1-lf	560	95 bc	95 a	93 bc	93 a
6	Clomazone	Pethoxamid + quinclorac	3-4 lf	420	100 a	94 ab	100 a	94 a
7	Clomazone	Pethoxamid + quinclorac	3-4 lf	560	100 a	96 a	98 ab	93 a
8	Clomazone	Pethoxamid + propanil	3-4 lf	420	100 a	90 a-d	100 a	79 b
9	Clomazone	Pethoxamid + propanil	3-4 lf	560	100 a	91 a-c	99 a	81 b
10	Clomazone	Pethoxamid + imazethapyr	3-4 lf	420	97 ab	93 a-c	100 a	93 a
11	Clomazone	Pethoxamid + imazethapyr	3-4 lf	560	100 a	94 ab	100 a	93 a
12	Clomazone	Pethoxamid + carfentrazone	3-4 lf	420	100 a	86 cd	98 ab	78 bc
13	Clomazone	Pethoxamid + carfentrazone	3-4 lf	560	100 a	87 b-d	100 a	78 bc
				P-value	0.0005	0.0297	<0.0001	<0.0001

† PRE = pre-emergence; POST = post-emergence.

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

Rice Flatsedge Control with Sharpen Tank-Mixtures in Mid-South Rice

R.R. Hale[1], J.K. Norsworthy[1], M.H. Moore[1], R.C. Scott[2], L.T. Barber[2], and J. Schultz[3]

Abstract

Heavy reliance of using acetolactate synthase-inhibiting herbicides for weed control has led to resistant biotypes of rice flatsedge (*Cyperus iria* L.), a common weed in mid-South rice production. Additional modes of action (MOA) must be used to slow the spread of such herbicide-resistant weeds. In 2014, Sharpen® (saflufenacil) was labeled for use in rice for preplant, pre-emergence (PRE), or post-emergence (POST) applications to help control problematic weeds. When plants are small (<8 cm) in height, Sharpen exhibits good control of rice flatsedge. However, the addition of a graminicide or other another herbicide in a tank mixture with grass activity will be needed to control grasses that are likely present within the same field. Field studies were conducted in 2015 and 2016 to examine the influence of application timing on the control of rice flatsedge by various tank mixtures including Sharpen at the University of Arkansas System Division of Agriculture's Pine Tree Research Station near Colt, Ark., and the Rice Research and Extension Center near Stuttgart, Arkansas. Herbicides included: Clincher, Ricestar HT, Stam M4, and Facet L. Herbicides were applied at preflood (PREFLD), 2 weeks after flood (2 WAF), and 4 WAF, and a nontreated control was included in each study. Herbicides were evaluated for efficacy alone and in combination with Sharpen. At 2 to 3 weeks after treatment (WAT) and 4 to 5 WAT, significantly greater control was observed when Sharpen was included in the tank mixture, except with Stam. By 4 to 5 WAT, tank mixtures of Sharpen + Clincher or Sharpen + Ricestar HT provided greater control. Based on these results, adding Sharpen to graminicides may be a viable tank-mix partner for additional control of rice flatsedge.

Introduction

Rice flatsedge is a common weed found in mid-South rice production. One rice flatsedge plant has the potential to produce 5000 seeds and is capable of reproducing

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multiple generations within a single rice crop (Galinato et al., 1999; Riar et al., 2015). Interference from the rice crop can reduce shoot biomass and inflorescence production of rice flatsedge, but complete control is not achieved due to an evolved physiological mechanism to elongate stems and avoid shading (Chauhan and Johnson, 2010; Riar et al., 2015). By the time rice flatsedge is often identified, rice yield losses may have already occurred (Chauhan and Johnson, 2010).

To combat rice flatsedge, there is heavy reliance on acetolactate synthase (ALS)-inhibiting herbicides such as bispyribac-sodium, halosulfuron, imazosulfuron, imazethapyr, and others (Riar et al., 2015; Scott et al., 2016). In imidazolinone (IMI)-resistant rice, imazethapyr (Newpath) applied pre-emergence (PRE) followed by post-emergence (POST) controlled barnyardgrass (*Echinochloa crus-galli* L. Beauv.) and rice flatsedge (≥98%) (Levy et al., 2006). However, clomazone (Command) applied at 1 pt/acre to rice at the spiking stage did not control rice flatsedge, but a subsequent application of halosulfuron at 0.37 oz ai/acre (26 g ai/ha) provided ≥90% control of rice flatsedge (Mudge et al., 2005). In 2010, rice flatsedge control was not achieved with applications of halosulfuron, and by 2014, sulfonylurea-resistant rice flatsedge was confirmed in the mid-South (Riar et al., 2015).

Aside from rice flatsedge, broadleaf weed species can be found in rice. Sharpen® (saflufenacil), a protoporphyrinogen oxidase (PPO)-inhibiting herbicide, controls broadleaf weeds and exhibits good control of rice flatsedge, but does not control grass weed species (Anonymous, 2015). There have been reports that when mixing a PPO-inhibiting herbicide like Aim® (carfentrazone), a current POST option for broadleaf control in Arkansas rice, with Newpath provided an increase in weed control and resulted in higher yield than Newpath alone (Montgomery et al., 2015; Zhang et al., 2006).

For both grass and broadleaf weeds, a successful herbicide tank mixture is dependent upon the effective performance of each herbicide applied alone, but an interaction between herbicides may occur when tank-mixed (Buehring et al., 2006; Myer and Coble, 1992). The evaluation of tank mixture combinations is often based on Colby's method using Eq. 1:

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

where *E* is the expected response when herbicide *A* and *B* are mixed. *A* is the weed efficacy with one herbicide applied alone, and *B* is the efficacy of another herbicide when applied alone (Colby, 1967). If an observed response is statistically greater than the calculated expected response, the particular herbicide tank mixture is synergistic. The herbicide response is deemed antagonistic if the inverse response is significant. If the expected and observed values are not statistically different, the combination for that tank mixture would be deemed additive (Colby, 1967).

Zhang et al. (2005) reported reductions in barnyardgrass control when tank-mixing Ricestar HT with Basagran (bentazon), Grandstand (triclopyr), or Aim. In POST situations, a single application of Clincher tank-mixed with a broadleaf herbicide would be beneficial, but previous reports of tank-mixing broadleaf herbicides with systemic herbicides that have the same or similar mode of action as Clincher often results in antagonistic interactions (Cantwell et al., 1989; Minton et al., 1989; Scott, 2003).

Although expensive, in salvage applications, where weeds have escaped preflood applications, applying a high rate of Facet L at 32 fl oz/acre and Stam at 3 or 4 qt/acre has been effective (Scott, 2003).

Procedures

Field studies were conducted to evaluate Sharpen tank-mixes with other rice herbicides on rice flatsedge control across application timings in 2015 and 2016 at the University of Arkansas System Division of Agriculture's Pine Tree Research Station near Colt, and in 2016 at the University of Arkansas System Division of Agriculture Rice Research and Extension Center near Stuttgart. The cultivar CL151 rice was drill-seeded at a rate of 22 seed/ft of row in 7-inch-wide rows into 6 ft × 17 ft plots. Rice herbicides were applied alone and tank-mixed with Sharpen at 1 fl oz/acre, which included Clincher (cyhalofop) at 15 oz/acre, Ricestar HT (fenoxaprop) at 24 oz/acre, Stam M4 (propanil) at 4 qt/acre, Facet L (quinclorac) at 43 oz/acre. Each treatment was applied at three application timings: PREFLD, 2 WAF, and 4 WAF. A nontreated control was included in each study and 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, the addition of Sharpen, and application timing. Data collection included visual assessments of rice injury and weed control 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 13 (SAS Institute Inc., Cary, N.C.), and means were separated using Fisher's protected least significant difference test ($P = 0.05$).

Results and Discussion

At 2 to 3 weeks after treatment (WAT; Fig. 1) and 4 to 5 WAT (Fig. 2), only a main effect of timing was significant for rice flatsedge control at 4 WAF (data not shown). An interaction of herbicide by Sharpen was significant at 2 to 3 WAT and 4 to 5 WAT. As expected, treatments of Clincher and Ricestar HT alone showed no control of rice flatsedge, because these products are acetyl CoA carboxylase (ACCase)-inhibiting herbicides and only control grass weed species. However, with the addition of Sharpen, rice flatsedge control for Clincher and Ricestar HT was 82% and 79%, respectively (Fig. 1). At 2 to 3 WAT, Facet L + Sharpen provided 81% control while Facet L alone only provided 71% control. At 2 to 3 WAT and at 4 to 5 WAT (Fig. 2), no statistical differences were observed between Stam alone and Stam + Sharpen.

Based on Colby's method for assessing herbicide interactions, antagonism was observed with tank mixtures consisting of Facet L + Sharpen and Stam + Sharpen (Table 1). Although an increase in control was observed with the addition of Sharpen to each graminicide, the tank mixtures were deemed additive, having no statistical difference between the calculated expected values and the observed values from the field.

Significance of Findings

The significance of this research is the finding that tank-mixing Sharpen with other common rice herbicides broadens the weed control spectrum. Tank-mixing Sharpen with graminicides resulted in a significant increase in control of rice flatsedge, but based on Colby's method, only an additive effect was observed. The addition of Sharpen did not reduce the control of Stam or Facet L, but the observed control for the tank-mixtures were deemed antagonistic based on Colby's method. It is important for growers to achieve high levels of rice flatsedge control and understand the impacts associated with ALS-resistant rice flatsedge that can limit herbicide options.

Acknowledgments

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Table 1. Rice flatsedge control 2 to 3 and 4 to 5 weeks after treatment (WAT), including the observed values from the field and the expected values provided by Colby's method.

	2 to 3 WAT		4 to 5 WAT	
Herbicide tank mixtures[†]	Expected	Observed	Expected	Observed
	-----	----- (%)	-----	-----
Clincher + Sharpen	79	82	84	86
Ricestar HT + Sharpen	79	79	84	81
Stam + Sharpen	94	83*[‡]	98	90*
Facet L + Sharpen	90	81*	94	82*

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

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

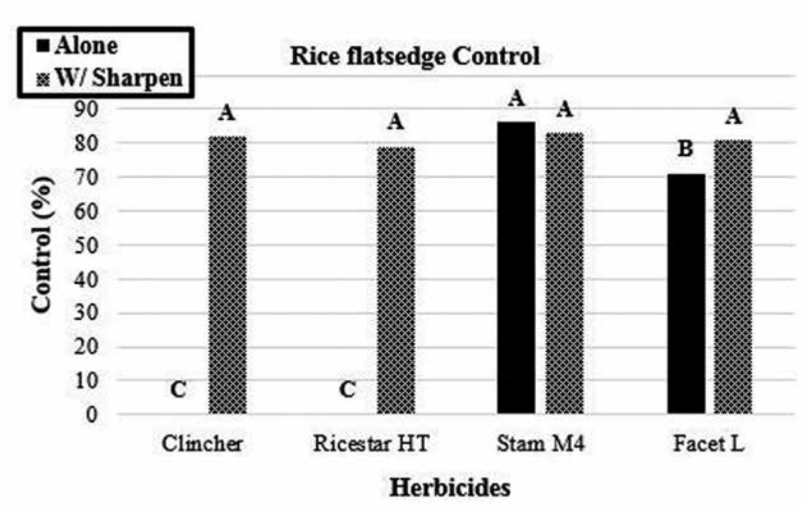

Fig. 1. Interaction of herbicides by Sharpen addition averaged over application timings and site years at 2 to 3 weeks after treatment. Letters used to separate means across herbicides (*P* = <0.0001).

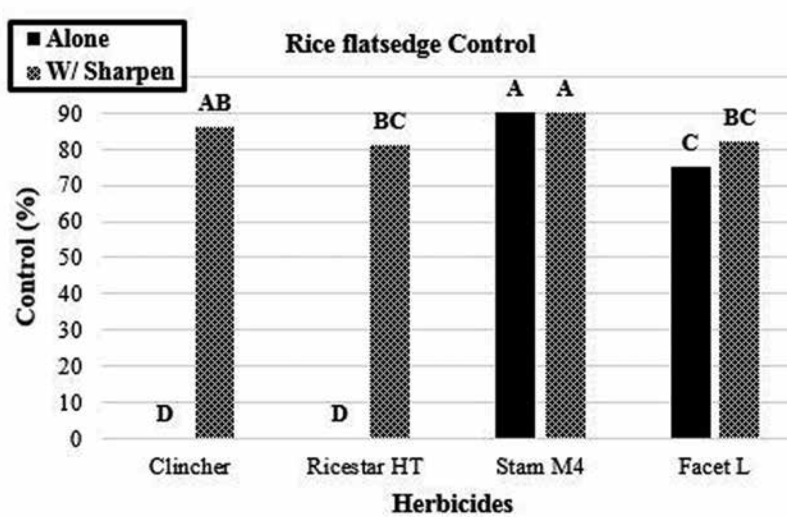

Fig. 2. Interaction of herbicides by Sharpen addition averaged over application timings and site years at 4 to 5 weeks after treatment. Letters used to separate means across herbicides (*P* = <0.0001).

Evaluation of Loyant™ Herbicide for the Control of Common Rice Weeds as a Single Application and as a Programs Approach

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Abstract

Heavy reliance on herbicides, such as propanil and quinclorac has resulted in widespread resistance to these two herbicides in barnyardgrass throughout large portions of Arkansas. Loyant™, a new herbicide has been shown to provide broad-spectrum post-emergence (POST) control of most broadleaf, grass, and sedge species commonly found in Arkansas rice. Two experiments were conducted on a Sharkey clay soil at University of Arkansas System Division of Agriculture's Rohwer Research Station, Rohwer, Ark., to evaluate the use of Loyant for the control of common rice weeds. These experiments were conducted as a randomized complete block design with four replications, where herbicide efficacy was evaluated for control of multiple weed species. The first experiment in 2015, consisted of treatments using Command applied pre-emergence (PRE) followed by (fb) Loyant plus multiple tank-mixes, and the second experiment in 2016, consisted of Command applied PRE fb Loyant™ and other common rice herbicides applied POST at 3 to 5 days pre-flood. In 2015, most herbicide programs provided >90% control of barnyardgrass throughout most of the season; however, very little control of Amazon sprangletop was observed from any program. In 2016, ≥85% control of barnyardgrass was observed for most treatments at 13 days after the pre-flood application. These data suggests that including Loyant into a rice weed management program will be highly beneficial in controlling common rice weeds.

Introduction

Rice production in Arkansas generally begins in early April, with 95% of rice planted by mid-May in order to achieve the highest percent of relative yield (Hardke et al., 2013). Over the past several decades, the increased use of propanil, quinclorac, and various acetolactate synthase inhibiting herbicides resulted in biotypes of barnyardgrass (*Echinochloa crus-galli*) being confirmed resistant to these herbicides (Heap, 2017). Loyant™ a new herbicide containing Rinskor™[3] active, is a new structural class of

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[3] Rinskor™ is not registered with the US EPA at the time of this presentation. The information presented is intended to provide technical information only and is not an offer for sale.

synthetic auxin herbicides in the arylpicolinate family (Miller et al., 2016). Previous research has shown that Loyant provides broad-spectrum post-emergence (POST) control of broadleaf, grass, and sedge species. Additionally, greenhouse work has shown that Loyant is active on herbicide-resistant barnyardgrass biotypes in Arkansas (Scott, 2016).

Procedures

Two experiments were conducted on a Sharkey Clay soil at the University of Arkansas System Division of Agriculture's Rohwer Research Station at Rohwer, Ark., to evaluate the use of Loyant for the control of common rice weeds. Both experiments were conducted as a randomized complete block design with four replications, where herbicide efficacy was evaluated for the control of barnyardgrass, Amazon sprangletop [*Leptochloa panicoides* (J. Presl) Hitchc.], and hemp sesbania [*Sesbania herbacea* (Mill.) McVaugh]. The first experiment in 2015, included treatments that contained Command applied pre-emergence (PRE) followed by (fb) Loyant tank-mixed with other common rice herbicides at either early post-emergence (EPOST), 3 to 5 days pre-flood, or 7 to 10 days post-flood. The second experiment in 2016, included treatments that contained Command applied PRE fb Loyant and other common rice herbicides applied post-emergence at 3 to 5 days pre-flood. 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

In 2015, 17 days after the pre-flood application, all programs provided >90% control of barnyardgrass; however, the lack of Amazon sprangletop control was evident with no program providing >63% control (Table 1). By 34 days after the post-flood application, most programs continued to provide >90% control of barnyardgrass (Table 2). These data suggests that applying Loyant post-flood did not provide additional control of barnyardgrass later in the season. In 2016, most treatments provided moderate control of barnyardgrass with 85% control 13 days after the pre-flood application (Table 3). When applied alone neither Loyant nor Newpath provided >90% control of barnyardgrass and Amazon sprangletop; however, when tank-mixing these herbicides the control of both species increased to >90%. By 35 days after the pre-flood application, Loyant alone provided >90% control of barnyardgrass; albeit, minimal suppression of Amazon sprangletop was observed (Table 4).

Significance of Findings

Throughout the course of the season, Loyant alone or in tank mixture provided moderate to effective control of both barnyardgrass and hemp sesbania. These data suggest that including Loyant in a rice weed management program will be beneficial in controlling troublesome weeds commonly found in Arkansas rice. However, this research also suggests that Loyant provides little to no control of Amazon sprangletop. Additionally, these data suggest that the ideal application timing to achieve effective control of common rice weeds is to apply Loyant within five days of the permanent flood.

Acknowledgments

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Table 1. Barnyardgrass and Amazon sprangletop control 17 days after the pre-flood application in 2015.

Program(s)[a]	Rate	Timing[b]	Weed control: Barnyardgrass	Weed control: Amazon sprangletop
	(lb ai/acre)		-------(%)-------	
Nontreated check			0	0
Command fb	0.4 fb 0.026	PRE fb	97	34
Loyant		3-5 d pre-flood		
Command fb Facet	0.4 fb 0.375 +	PRE fb EPOST fb	97	51
L + Loyant fb	0.026 fb			
Loyant	0.026	3-5 d pre-flood		
Command fb	0.4 fb 0	PRE fb	99	63
Facet L + RiceShot	.375 + 3	EPOST		
fb Loyant	fb 0.026	fb 3-5 d pre-flood		
Command fb	0.4 fb	PRE fb	93	21
Facet L + Loyant	0.375 + 0.026	EPOST		
Command fb	0.4 fb	PRE fb	96	44
Loyant	0.026	3-5 d pre-flood		
Command fb	0.4 fb 0.	PRE fb	97	31
Facet L + Loyant	375 + 0.026	EPOST fb		
fb Grasp SC	fb 0.0356	3-5 d pre-flood		
Command fb	0.4 fb	PRE fb	97	19
RebelEX	0.286	3-5 d pre-flood		
Command fb	0.4 fb	PRE fb	99	51
Permit + RiceShot	0.047 + 3	EPOST fb		
fb Loyant	fb 0.026	3-5 d pre-flood		
Command fb	0.4 fb	PRE fb	99	51
Facet L + Prowl	0.375 + 0.95 fb	EPOST fb		
H_2O fb Permit + RiceBeaux	0.047 + 4.5	3-5 d pre-flood		
Command fb	0.4 fb	PRE fb	99	46
Facet L + Prowl H2O fb	0.375 + 1.0 fb	EPOST fb		
Permit + Loyant	0.047 + 0.026	3-5 d pre-flood		

continued

Table 1. Continued.

Program(s)[a]	Rate	Timing[b]	Weed control	
			Barnyardgrass	Amazon sprangletop
	(lb ai/acre)		-------------------- (%) --------------------	
Command fb	0.4 fb	PRE	95	28
Facet L + Grandstand	0.375 + 0.375	fb		
+ RiceShot	+ 3	3-5 d pre-flood		
Command fb	0.4 fb	PRE fb	97	28
Facet L + Loyant		3-5 d pre-flood fb		
	0.375 + 0.026	7-10 d post-flood		
$LSD_{0.05}$			6.2	13.5

[a] All post-emergence treatments were applied with 1.0% crop oil concentrate, except for those containing RiceShot.

[b] PRE = pre-emergence; EPOST = early post-emergence; fb = followed by.

Table 2. Barnyardgrass and Amazon sprangletop control 34 days after the post-flood application in 2015.

			Weed control	
Program(s)[a]	Rate	Timing[b]	Barnyardgrass	Amazon sprangletop
	(lb ai/acre)		----(%)----	
Nontreated check			0	0
Command fb	0.4 fb	PRE FB	95	14
Loyant	0.026	3-5 d pre-flood		
Command fb	0.4 fb	PRE fb	93	29
Facet L + Loyant fb	0.375 + 0.026 fb	EPOST fb		
Loyant	0.026	3-5 d pre-flood		
Command fb	0.4 fb	PRE fb	96	36
Facet L + RiceShot fb	0.375 + 3 fb	EPOST fb		
Loyant	0.026	3-5 d pre-flood		
Command fb	0.4 fb	PRE fb	74	13
Facet L + Loyant fb	0.375 + 0.026 fb	EPOST fb		
Loyant	0.026	7-10 d post-flood		
Command fb	0.4 fb	PRE fb	93	28
Loyant fb	0.026 fb	3-5 d pre-flood fb		
Clincher	0.28	7-10 d post-flood		
Command fb	0.4 fb	PRE fb	85	10
Facet L + Loyant fb	0.375 + 0.026 fb	EPOST fb		
Grasp SC fb	0.0356 fb	3-5 d pre-flood fb		
Clincher	0.28	7-10 d post-flood		
Command fb	0.4 fb	PRE fb	72	8
RebelEX fb	0.286 fb	3-5 d pre-flood fb		
Loyant	0.026	7-10 d post-flood		
Command fb	0.4 fb	PRE fb	95	40
Permit + RiceShot fb	0.047 + 3 fb	EPOST fb		
Loyant	0.026	3-5 d pre-flood		

continued

Table 2. Continued.

Program(s)[a]	Rate	Timing[b]	Weed control	
			Barnyardgrass	Amazon sprangletop
	(lb ai/acre)		----------(%)----------	
Command fb	0.4 fb	PRE fb	97	25
Facet L + Prowl H_2O fb	0.375 + 0.95 fb	EPOST fb		
Permit + RiceBeaux fb	0.047 + 4.5 fb	3-5 d pre-flood fb		
Clincher	0.28	7-10 d post-flood		
Command fb	0.4 fb	PRE fb	90	21
Facet L + Prowl H_2O fb	0.375 + 1.0 fb	EPOST fb		
Permit + Loyant fb	0.047 + 0.026 fb	3-5 d pre-flood fb		
Clincher	0.28	7-10 d post-flood		
Command fb	0.4 fb	PRE fb	95	26
Facet L + Grandstand +	0.375 + 0.375	3-5 d pre-flood fb		
RiceShot fb Clincher	+ 3 fb 0.28	7-10 d post-flood		
Command fb	0.4 fb	PRE fb	83	16
Facet L + Loyant fb	0.375 + 0.026 fb	3-5 d pre-flood fb		
Clincher	0.28	7-10 d post-flood		
$LSD_{0.05}$			21.7	12.2

[a] All post-emergence treatments were applied with 1.0% COC, except for those containing RiceShot.
[b] PRE = pre-emergence; EPOST = early post-emergence; fb = followed by.

Table 3. Barnyardgrass, amazon sprangletop, and hemp sesbania control 13 days after the pre-flood application in 2016.

			Weed control		
Treatment(s)[a, b]	Rate	Timing[b]	Barnyardgrass	Amazon sprangletop	Hemp sesbania
	(lb ai/acre)		----------	(%)	----------
Nontreated check			0	0	0
Command fb	0.8 fb	PRE fb	83	70	97
Loyant	0.026	3-5 d pre-flood			
Command fb	0.8 fb	PRE fb	69	48	93
Facet L*	0.375	3-5 d pre-flood			
Command fb	0.8 fb	PRE fb	86	88	30
Newpath*	0.094	3-5 d pre-flood			
Command fb	0.8 fb	PRE fb	85	85	99
Facet L + Stam M4	0.375 + 3	3-5 d pre-flood			
Command fb	0.8 fb	PRE fb	83	81	24
RiceStar HT	0.127	3-5 d pre-flood			
Command fb	0.8 fb	PRE fb	81	80	33
Clincher	0.28	3-5 d pre-flood			
Command fb	0.8 fb	PRE fb	36	30	90
Permit*	0.0625	3-5 d pre-flood			
Command fb	0.8 fb	PRE fb	86	58	98
Grasp	0.0356	3-5 d pre-flood			
Command fb	0.8 fb	PRE fb	86	65	98
Grasp XTRA	0.325	3-5 d pre-flood			
Command fb	0.8 fb	PRE fb	85	78	97
Loyant + Facet L	0.026 + 0.375	3-5 d pre-flood			
Command fb	0.8 fb	PRE fb	87	83	97
Loyant + Clincher	0.026 + 0.28	3-5 d pre-flood			
Command fb	0.8 fb	PRE fb	94	91	99
Loyant + Newpath	0.026 + 0.094	3-5 d pre-flood			
Command fb	0.8 fb	PRE fb	90	83	99
Penoxsulam + Loyant	0.058 + 0.026	3-5 d pre-flood			
$LSD_{0.05}$			10.7	10.2	11

[a] Most post-emergence treatments were applied with either 2.0% methylated seed oil or 1.0% crop oil concentrate*.
[b] PRE = pre-emergence; EPOST = early post-emergence; fb = followed by.

Table 4. Barnyardgrass, Amazon sprangletop, and Hemp sesbania control 35 days after the pre-flood application in 2016.

			Weed control		
Treatment(s)[a,b]	Rate	Timing[b]	Barnyardgrass	Amazon sprangletop	Hemp sesbania
	(lb ai/acre)		----------	(%)	----------
Nontreated check			0	0	0
Command fb	0.8 fb	PRE fb	91	41	99
Loyant	0.026	3-5 d pre-flood			
Command fb	0.8 fb	PRE fb	84	35	97
Facet L	0.375	3-5 d pre-flood			
Command fb	0.8 fb	PRE fb	95	97	0
Newpath	0.094	3-5 d pre-flood			
Command fb	0.8 fb	PRE fb	91	96	99
Facet L + Stam M4	0.375 + 3	3-5 d pre-flood			
Command fb	0.8 fb	PRE fb	91	96	0
RiceStar HT	0.127	3-5 d pre-flood			
Command fb	0.8 fb	PRE fb	93	96	0
Clincher	0.28	3-5 d pre-flood			
Command fb	0.8 fb	PRE fb	29	45	99
Permit	0.0625	3-5 d pre-flood			
Command fb	0.8 fb	PRE fb	95	43	99
Grasp	0.0356	3-5 d pre-flood			
Command fb	0.8 fb	PRE fb	91	36	99
Grasp XTRA	0.325	3-5 d pre-flood			
Command fb	0.8 fb	PRE fb	90	76	99
Loyant + Facet L	0.026 + 0.375	3-5 d pre-flood			
Command fb	0.8 fb	PRE fb	79	84	99
Loyant + Clincher	0.026 + 0.28	3-5 d pre-flood			
Command fb	0.8 fb	PRE fb	88	90	99
Loyant + Newpath	0.026 + 0.094	3-5 d pre-flood			
Command fb	0.8 fb	PRE fb	93	80	99
Penoxsulam + Loyant	0.058 + 0.026	3-5 d pre-flood			
$LSD_{0.05}$			11.3	15.8	2

[a] Most post-emergence treatments were applied with either 2.0% methylated seed oil or 1.0% crop oil concentrate*.
[b] PRE = pre-emergence; EPOST = early post-emergence; fb = followed by.

Efficacy and Rice Tolerance of Tank Mixes Containing Topramezone (Armezon®)

M.H. Moore[1], R.C. Scott[2], J.K. Norsworthy[1], M.E. Fogleman[1], and J.A. Godwin Jr.[1]

Abstract

Field trials were conducted in the summer of 2016 to evaluate efficacy and rice tolerance to topramezone (Armezon® 2.8L) herbicide. Treatments in these trials included Armezon applied alone at 0.5 and 1.0 fl oz/acre and in combination with 32 fl oz/acre of Facet L (quinclorac), 24 fl oz/acre of Ricestar HT (fenoxaprop), 4 qt/acre of Riceshot (propanil), 6 fl oz/acre of Newpath (imazethapyr), 1 fl oz/acre of Sharpen (salfufenacil), or 0.8 pt/acre of Command 3ME (clomazone). All treatments for both field experiments were applied at the 3- to 4-leaf (lf) rice stage. In the rice tolerance trial, all treatments resulted in less than 5% injury 14 days after treatment (DAT), with the exception of the treatments containing Ricestar HT which resulted in injury of 10% or less. Each subsequent rating (28 and 42 DAT) resulted in injury ≤5% for all tank mixes. In the efficacy trial, treatment results varied; 28 DAT the addition of Armezon increased the barnyardgrass control at both high (93%) and low (90%) rates when applied with Command and at the 1 fl oz/acre rate when applied with Newpath (93%). Inversely, the efficacy of Armezon was reduced when applied with Riceshot and Sharpen, likely because of antagonism from the contact herbicides.

Introduction

Barnyardgrass (*Echinochloa crus-galli*) is one of the most troublesome weeds in Arkansas rice production. If left uncontrolled, barnyardgrass can cause yield losses of up to 80% in a production field (Norsworthy et al., 2013b; Smith, 1988). Currently, barnyardgrass is known to have evolved widespread resistance to five herbicide sites of action commonly used in rice weed control including the ACCase (WSSA Group 1), ALS (WSSA Group 2), synthetic auxin (WSSA Group 4), PPO (WSSA Group 7), and DOXP (WSSA Group 13) (Norsworthy et al., 2013a; Wilson et al., 2014).

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In recent years, research has been conducted on a post-flood 4-hydroxyphenyl-pyruvate dioxygenase (HPPD) inhibitor (WSSA Group 27), benzobicyclon, in rice. Although the herbicide has shown promise in controlling several key weeds, it only provides suppression of barnyardgrass (Young et al., 2016). This has led to research on another HPPD-inhibiting herbicide, topramezone, which has been used in corn for annual grass control, including barnyardgrass (Grossman and Ehrhardt, 2007). Early research in rice resulted in successful control of barnyardgrass and low amounts of crop injury from topramezone (Scott et al., 2016). If labeled, topramezone would provide producers with a new site of action for aiding in preventing the further spread of herbicide-resistant barnyardgrass.

The objective of this research was to further evaluate the efficacy of topramezone on barnyardgrass and crop tolerance in rice when applied alone and in tank mixes applied early-post-emergence.

Procedures

Field experiments were conducted in 2016 at the University of Arkansas at Pine Bluff Research Farm located near Lonoke, Ark. The soil texture was a silt loam with a pH of 6.3. Clearfield rice (CL151) was drill-seeded on 18 May 2016 at a seeding rate of 90 lb/acre on 7.5-in.-wide rows. Plot sizes were 6 ft × 20 feet. Both studies were conducted with a randomized complete block design containing four replications.

Treatments consisted of topramezone in the form of Armezon (2.8 lb ai/gal) applied alone at 0.50 and 1.0 fl oz/acre and in combination with 32 fl oz/acre of Facet L, 24 fl oz/acre of Ricestar HT, 4 qt/acre of Riceshot LC, 6 fl oz/acre of Newpath, 1 fl oz/acre of Sharpen, or 0.8 pt/acre of Command 3ME. Treatments were applied early-post-emergence when the rice was at the 3-lf growth stage with a CO_2-pressurized backpack sprayer calibrated to deliver 15 gal/acre. Plots in the tolerance trial were kept weed free and in the efficacy trial barnyardgrass (2- to 4-lf) was present at 3 plants/ft^2. All treatments included 1% v/v crop oil concentrate except for those containing Riceshot. All plots were grown according to the University of Arkansas System Division of Agriculture Cooperative Extension Service recommendations.

Data collected included percent visible injury and control ratings for barnyardgrass 14, 28, and 42 days after treatment (DAT). Data were analyzed and a Fisher's protected least significant difference test was used to separate means at $P = 0.05$ using JMP Pro 12.

Results and Discussion

Armezon applied alone at 0.5 to 1.0 fl oz/acre and in the various tank mixtures resulted in less than 5% injury at all times evaluated, with the exception of Ricestar HT (24 fl oz/acre) plus Armezon 1.0 fl oz/acre which resulted in a 10% injury 14 DAT (Table 1). Based on these data, the rice variety evaluated, CL151, expressed tolerance to topramezone near the proposed labeled rates. Further studies are needed to look at multiple germplasms of rice and include both rates (0.5 and 1.0 oz/acre) of Armezon.

Armezon applied alone at 0.5 and 1.0 fl oz/acre provided up to 78 and 85% barnyardgrass control 14 DAT. However, at 28 and 42 DAT control was reduced suggesting that Armezon has minimal residual activity on barnyardgrass. The addition of Armezon did not increase the amount of weed control in the tank mixes including Facet or Ricestar, both of which had 90% control or more without the addition of Armezon. Ratings also show the addition of Armezon at 1.0 fl oz/acre did increase barnyardgrass control in tank-mixes containing herbicides with residual effects similar to what was seen with Newpath and Command at all ratings (14, 28, and 42 DAT). The addition of Sharpen or Riceshot to Armezon resulted in a reduction of barnyardgrass control compared to Armezon alone. This barnyardgrass control data closely resembles previous studies done in rice and corn, respectively (Scott et al., 2016; Grossman and Ehrhardt, 2007)

Significance of Findings

The results of this study indicate that it is possible to include topramezone in an Arkansas drill-seeded rice production system. Control of barnyardgrass was observed when topramezone was applied alone and in combination with other herbicides. Based on the results of this research, topramezone was most effective when combined with a residual herbicide. Tank-mixes containing contact herbicides such as Sharpen and Riceshot should be avoided due to the reduction in barnyardgrass control. This could lead to a new mode of action for control of this weed which would significantly help in the fight against resistant biotypes. These studies will be replicated during the summer of 2017 to further replicate these findings.

Acknowledgments

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Table 1. Rice injury and barnyardgrass control at 14 , 28, and 42 days after treatment (DAT).

		Visible injury			Barnyardgrass control		
Treatment	**Herbicide rate**	**14 DAT**	**28 DAT**	**42 DAT**	**14 DAT**	**28 DAT**	**42 DAT**
	(per acre)	(%)					
Armezon	0.50 fl oz	0	0	0	78 def[†]	67 ef	57 cd
Armezon	1.00 fl oz	0	0	0	85 bcd	78 cd	66 bc
Facet L	32.0 fl oz	0	0	0	90 abc	90 ab	88 a
Facet L+ Armezon	32.0 fl oz + 1.00 fl oz	2	0	0	93 a	96 a	95 a
Facet L + Armezon	32.0 fl oz + 0.50 fl oz	0	0	0	93 a	93 ab	93 a
Ricestar HT	24.0 fl oz	5	0	0	90 abc	92 ab	91 a
Ricestar HT + Armezon	24.0 fl oz + 1.00 fl oz	10	5	0	92 ab	93 ab	94 a
Ricestar HT + Armezon	24.0 fl oz + 0.50 fl oz	8	5	0	90 abc	94 ab	90 a
Riceshot	4.00 qt	0	0	0	37 i	24 i	12 g
Riceshot + Armezon	4.00 qt + 1.00 fl oz	0	0	0	76 fg	71 def	52 de
Riceshot + Armezon	4.00 qt +0.50 fl oz	0	0	0	65 h	35 h	13 g
Newpath	6.00 fl oz	0	0	0	85 bc	75 cde	73 b
Newpath + Armezon	6.00 fl oz + 1.00 fl oz	0	0	0	93 a	94 ab	90 a
Newpath + Armezon	6.00 fl oz + 0.50 fl oz	0	0	0	85 bc	85 bc	75 b
Sharpen	1.00 fl oz	0	0	0	36 i	26 hi	18 g
Sharpen + Armezon	1.00 fl oz + 1.00 fl oz	0	0	0	70 gh	65 f	42 ef
Sharpen + Armezon	1.00 fl oz + 0.50 fl oz	0	0	0	69 gh	63 f	50 def
Command	0.80 pt	0	0	0	77 ef	52 g	40 f
Command + Armezon	0.80 pt + 1.00 fl oz	0	0	0	93 ab	97 a	95 a
Command + Armezon	0.80 pt + 0.50 fl oz	0	0	0	89 abc	93 ab	90 a

[†] Means followed by the same letter are not significantly different at $P = 0.05$ based on Fisher's protected least significant difference test.

Comparison of Simulated Drift Rates of Common Rice Herbicides to Rinskor™ Active on Soybean

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Abstract

Acetolactate synthase (ALS)-herbicides are among the most commonly used sites of action (SOA) in rice production today. These herbicides can be injurious to soybean, which is commonly grown near rice fields or rotated with rice, through carryover or drift. The introduction of Loyant™ herbicide with Rinskor™ Active brings an alternative SOA to rice production. The objective of this study was to determine the effects of various drift rates of Rinskor and other commonly used ALS-inhibiting herbicides on soybean. A field study conducted in 2016 at two locations examining five ALS-inhibiting herbicides as well as Rinskor Active at 1/20× and 1/80× simulated drift rates. Crop injury was evaluated at 14, 21, and 35 days after treatment (DAT), as well as yield. Rinskor and Regiment both showed high injury levels to soybean at both drift rates with little dissipation of injury over time. At 35 DAT, Rinskor showed crop injury levels of 76% (1/20) and 17% (1/80×); whereas Regiment had injury levels of 35% and 9% at 1/20× and 1/80×, respectively. These treatments also had a significant effect on yield. In comparison to the control (44 bu/acre), Rinskor Active at the 1/20× and 1/80× drift rates yielded only 8 and 33 bu/acre, respectively. Although this alternative SOA in rice may be effective in weed control, it can be injurious to soybean and proper precautions should be made to avoid drift to adjacent soybean crops.

Introduction

In the mid-southern U.S., soybean (*Glycine max*) is frequently grown in close proximity to rice or commonly rotated with rice (*Oryza sativa*) (Wilson et al., 2010). Common rice herbicides, such as acetolactate synthase (ALS)-inhibitors, can consequently cause injury to soybean through drift. The overreliance of herbicides in the same sites of action (SOA), such as ALS-inhibitors, has led to many weed species evolving resistance to herbicides having this SOA (Norsworthy et al., 2013). For example, in the United States (U.S.), there are ten weeds, in rice, that are resistant to

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ALS-inhibitors (Heap, 2017). Thus, a new herbicide SOA is needed in rice production that will not only limit the frequency of resistance on weed species, but that will also limit any injury to soybean.

Loyant™ herbicide with Rinskor™ Active (Dow AgroSciences) is a new herbicide that would provide an alternative SOA (synthetic auxins in the arylpicolinate herbicide family) in rice that is capable of achieving a high level of weed control, especially ALS-resistant sedges (Miller and Norsworthy, 2016). This new herbicide provides broad-spectrum, post-emergence control of broadleaf, grass, and sedge species (Weimer et al., 2015). Furthermore, previous research supports a relatively short (about 60 days) plant-back interval for soybean after Rinskor application compared to other herbicides commonly used in rice (Miller et al., 2016). However, there is no research on injury caused by Rinskor drift onto soybean. Thus, the objective of this study was to determine the effects of various drift rates of Rinskor and other commonly used ALS-inhibiting herbicides on soybean.

Procedures

A field experiment was conducted during 2015 at the University of Arkansas System Division of Agriculture's Arkansas Agricultural Experiment Station (AAES) in Fayetteville, Ark., and at the Pine Tree Research Station (PTRS) near Colt, Ark. (two site years). Plots at both research stations, measured 12 ft × 20 ft and were planted with Pioneer 95L01 soybean, a non-ALS-tolerant soybean variety. The experiment was arranged as a randomized complete block design with four replications. The trial was kept weed free.

Treatments consisted of five ALS-inhibiting herbicides: bispyribac (Regiment) with a 1× rate of 0.024 lb/acre, penoxsulam (Grasp) with a 1× rate of 0.032 lb/acre, halosulfuron (Permit) with a 1× rate of 0.036 lb/acre, orthosulamuron (Strada) with a 1× rate of 0.062 lb/acre, and imazolsulfuron (League) with a 1× rate of 0.304 lb/acre; as well as Rinskor Active with a 1× rate of 0.027 lb/acre, and a nontreated control. Each herbicide was applied at two simulated drift rates of 1/20× and 1/80× with Rinskor Active, Regiment, and Grasp containing a 1% v/v of methylated seed oil (MSO), Permit containing a 1% v/v crop oil concentrate (COC), and Strada and League containing a 0.25% v/v non-ionic surfactant (NIS). The simulated drift rates were made from a 1× stock solution of each herbicide. The treatments were applied at the V3 growth stage with a CO_2-backpack sprayer calibrated to deliver 15 gal/acre. Data collection included estimates of visual injury on a scale of 0% to 100%, with 0% representing no injury and 100% representing complete crop death at 14, 21, and 35 days after treatment (DAT). In addition, grain yield was determined by harvesting the two treated rows. 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

There was no significant difference between site years, thus they were pooled. There was a highly significant interaction ($P = 0.002$) between drift rate and DAT for each treatment (Table 1). All treatments resulted in initial injury, with the 1/20× drift rate having higher injury than the 1/80× drift rate. By 21 DAT, there was no significant difference between drift rates within a treatment except for Rinskor Active and Regiment. Regardless of DAT or drift rate, Rinskor Active was more injurious to the soybean. For example, visual ratings resulted in 71% and 76% crop injury and 31% and 17% at 21 and 35 DAT for the 1/20× and 1/80× drift rates, respectively. Regiment also exhibited a higher level of crop injury than the other ALS-inhibiting herbicides, at 21 DAT for both drift rates, (1/20×: 35%; 1/80×: 12%) and at 35 DAT (1/20×: 35%; 1/80×: 9%). Although crop injury was high for both treatments at 35 DAT, there was not a significant difference in crop height at this time or at harvest (data not shown).

High crop injury had a significant effect on yield. The nontreated control yielded 44 bu/acre (Table 1); whereas Rinskor Active and Regiment yielded 8 and 33 bu/acre at the 1/20× drift rate and 19 and 45 bu/acre at the 1/80× drift rate. The other 4 ALS-inhibiting herbicides did not differ in yield from the nontreated control at either drift rate. Although Rinskor Active may be highly effective in weed control (Miller and Norsworthy, 2016), this new SOA will need to be used in rice with much caution because soybean in close proximity to rice is at high risk for injury.

Significance of Findings

The significance of this research is primarily to understand the effects of a new SOA in rice on soybean through drift, as soybean is commonly grown in close proximity or planted in rotation to rice. Although the Loyant herbicide with Rinskor Active will provide mid-southern rice growers with an alternative herbicide SOA that is capable of achieving a high level of weed control, it has shown to be highly injurious to soybean at a low (1/80×) and high (1/20×) drift rate. Furthermore regardless of drift rates, soybean yield was significantly lowered in comparison to the nontreated control. Caution should be used when applying Rinskor Active when soybean is in close proximity. However this work does indicate that Loyant poses no greater risk to non-ALS-tolerant soybean than Regiment herbicide which is already labeled for us in Arkansas rice.

Acknowledgments

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Table 1. Effects of 5 acetolactate synthase (ALS)-inhibiting herbicides and Rinskor Active at two simulated drift rates (1/20× and 1/80×) 14, 21, and 35 days after treatment (DAT). Sites were not significantly different and have been pooled.

Treatment	Drift rate	14 DAT	21 DAT	35 DAT	Yield
		----------------------	(%)	----------------------	(bu/acre)
Nontreated	–	0	0	0	44
Rinskor Active	1/20×	78	71	76	8
Regiment		36	35	35	19
Grasp		14	10	5	37
Permit		11	7	2	43
Strada		17	9	6	40
League		19	16	12	44
Rinskor Active	1/80×	40	31	17	33
Regiment		15	12	9	45
Grasp		8	8	1	40
Permit		7	7	3	37
Strada		6	5	4	44
League		6	5	4	41
LSD (P = 0.05)		6	7	6	9

2016 Degree-Day 50 Thermal Unit Thresholds for New Rice Cultivars and Planting Date Studies

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Abstract

The Degree-Day 50 (DD50) Rice Management Program has become one of the most successful management aids developed by the University of Arkansas System Division of Agriculture. This program predicts critical growth stages that assist in increasing the effectiveness of crop management operations. In order to be relevant, the computer program must be updated continually as new rice cultivars become available. In pursuit of 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 2016 season, DD50 thermal unit accumulation, developmental data, and the effect of seeding date on grain and milling yield potential data for twenty cultivars were evaluated over five seeding dates under a dry-seeded, delayed-flood management system that is commonly used in southern U.S. rice production.

Introduction

The Degree-Day 50 (DD50) Rice Management Program is a modification of the growing degree-day concept, daily high and low air temperatures are used to measure a day's thermal quality for plant growth. Developed in the 1970s to help farmers time midseason nitrogen (N) applications with precision, the DD50 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.

Beginning at emergence, the DD50 Program generates a predicted rice plant development file that is cultivar-specific based on the accumulation of DD50 units. The initial file is created by calculating thermal unit accumulation using 30-year average weather data collected by the National Weather Service weather stations closest to a

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rice producer's location in Arkansas. As the season progresses the program is updated with the current year's weather data on a daily basis for improved accuracy.

The data used to predict plant development for a specific cultivar is generated in yearly studies where promising experimental lines and newly released rice cultivars are evaluated in four to six planting 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 Rice Management Program that enables the prediction of dates of plant developmental stage occurrences and prediction of dates when particular management practices are recommended to be performed. Therefore, the objectives of this study were to develop a DD50 thermal accumulation database for promising new cultivars, verification and refinement of the existing database of current cultivars, and assessment of the effect of seeding date on DD50 thermal unit accumulation. Additionally, the effects of seeding date on the grain and milling yields of a particular cultivar were measured in order to determine optimal seeding dates that enhance these yields.

Procedures

The 2016 season 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. Fourteen pure-line cultivars (CL111, CL151, CL153, CL163, CL172, CL272, Diamond, Jupiter, LaKast, Mermentau, Roy J, Thad, Titan, and Wells) were dry-seeded at a rate of 30 seed/ft^2 in plots 9 rows wide (7-in. spacing) and 15 ft long. Six hybrids (RT 7311 CL, RT CLXL729, RT CLXL745, RT Gemini 214 CL, RT XL753, and RT XL760) were seeded into plots of the same dimensions using the reduced seeding rate for hybrids (10.3 seed/ft^2). The seeding dates for 2016 were 22 March, 5 April, 23 April, 6 May, 23 May, and 9 June. Bird depredation resulted in the loss of the 23 May seeding date, and unfortunate events prevented the collection of a full set of data for the 9 June seeding date. General agronomic information is shown in Table 1. Cultural practices established for dry-seeded, delayed-flood rice production were followed. A single preflood application of 130 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 the 22 March, 5 April, 23 April, and 6 May seeding dates included: maximum and minimum temperatures, date of seedling emergence, and the number of days and DD50 units required to reach 50% heading. The number of days and DD50 thermal units required to reach 0.5-in. internode elongation (IE) was also collected for the 22 March, 23 April, and 9 June seeding dates. At maturity, the 5 center rows in each plot were harvested, weight of grain and moisture content were recorded, and a subsample of harvested grain was taken for milling purposes on all seeding dates. The grain yield was adjusted to 12% moisture and reported on a bushels/acre (bu/acre) basis. The dry rice was milled to obtain percent of head rice (%HR; whole kernel) and percent of total white rice (%TR). The arrangement of each seeding date corresponded to a randomized complete block design with four replications. Statistical analyses were conducted using PROC GLM v. 9.4 (SAS Institute, Cary, N.C.) and mean separation conducted using Fisher's protected least significant difference test ($P = 0.05$) where appropriate.

Results and Discussion

Times between seeding and emergence ranged from 7 to 20 days (Table 1) directly affecting the required days from seeding to flooding. In general, seeding date (SD) studies report a decrease in days between seeding and emergence as the seeding date is delayed; the 2016 study followed this general trend of decreasing days from seeding to emergence as SD was delayed from late March to early May and early June. The time from seeding to establishment of the permanent flood followed the same trend as the SD was delayed, ranging from 43 days for the 22 March SD to 24 days for the 23 May SD and increased to 28 days for the early June SD. The times from emergence to flooding in 2016 did not follow the same trend as SD was delayed. The first four SDs required a similar span of time from emergence to flooding (23 to 24 days). The 23 May SD required a shorter time interval of 17 days an then increased to 21 days for the 9 June SD. These results alone underscore the importance of the effect of seasonal variation of weather conditions on the overall growth and development of the rice crop as well as the need to continually update the DD50 thermal unit thresholds.

The days required from emergence to 0.5-inch IE are listed in Table 2 and encompass three SDs during 2016. Across cultivars, the average number of days to reach 0.5-inch IE was 51 days and ranged from 59 days when seeded in late March to 41 days when seeded in early June. A decreasing trend in time required to reach 0.5-inch IE as SD was delayed was observed. Time required for vegetative growth averaged across SDs was 51 days, ranging from 63 days in late March for CL272 to 36 days in June for RT7311CL. The DD50 thermal unit accumulation for vegetative growth averaged across SD ranged from a low of 1116 for RT 7311 CL to a high of 1312 for Thad.

The time needed to reach the developmental stage known as 50% heading from the time of seeding averaged across SD and cultivars was 83 days (Table 3). The average time for cultivars to reach 50% heading ranged from 87 days when seeded in late March to 78 days when seeded in early May. For individual cultivars, the time required to reach 50% heading ranged from 93 days for CL272, Jupiter, and Roy J when seeded in late March to 73 days for LaKast, RT7311CL, and XL753 when seeded in early May. For 2016, the thermal unit accumulation from emergence to 50% heading averaged 2111 across SD and cultivars. The individual cultivar accumulation of DD50 thermal units, from emergence to 50% heading, ranged from a low of 1844 for RTCLXL745 seeded 22 March to a high of 2358 for CL163 seeded 6 May, and was generally higher for most cultivars seeded 6 May.

Average grain yield for the 2016 study was 192 bu/acre (Table 4). When averaged across cultivars, grain yield was highest when seeded on 22 March and lowest when seeded 6 May and 9 June. Similar grain yields for the 6 May and 9 June SDs were observed with a tendency for yields to decrease as the seeding date was delayed. All hybrid cultivars averaged greater than 200 bu/acre across the five SDs while Diamond was the only non-hybrid cultivar to average at least 200 bu/acre across the SDs. The most consistent cultivars across the five SDs were RTCLXL745, LaKast, RTXL760, RTCLXL729, and Roy J.

During 2016, the milling yield, %HR and %TR, averaged across SD and all cultivars was 62% HR and 71% TR (Table 5). In general, %HR decreased in the 23 April and 6 May SDs, then increased in the 9 June SD compared to the two SDs of 22 March and 5 April. No trend was observed for changes in %TR based on SD during 2016.

Significance of Findings

The data obtained during 2016 will be used to improve the database of thermal unit thresholds in the DD50 Rice Management Program for new cultivars being grown. The grain and milling yield data contributes 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.

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Table 1. General seeding, seedling emergence, and flooding date information for the DD50 seeding date study in 2016 at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center near Stuttgart, Ark.

	Seeding date					
	22 March	5 April	23 April	6 May	23 May	9 June
Emergence date	14 April	6 May	15 May	27 May	10 June	22 June
Emergence date	12 April	19 May	1 May	14 May	30 June	16 June
Flood date	5 May	12 May	24 May	7 June	16 June	7 July
Days from seeding to emergence	20	14	8	8	7	7
Days from seeding to flooding	43	37	31	32	24	28
Days from emergence to flooding	23	23	23	24	17	21

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 University of Arkansas System Division of Agriculture's Rice Research and Extension Center during 2016.

	Seeding date							
	22 March		23 April		9 June		Average	
Cultivar	days	DD50[a] units	days	DD50 units	days	DD50 units	days	DD50 units
CL163	60	1229	54	1307	44	1337	52	1291
CL172	60	1229	53	1292	40	1204	51	1241
CL272	63	1327	54	1322	42	1286	53	1311
CL153	57	1163	50	1177	38	1142	48	1161
Diamond	61	1259	54	1307	42	1286	52	1284
LaKast	60	1229	53	1284	40	1212	51	1242
RT7311CL	56	1121	48	1124	36	1102	47	1116
RT Gemini 214CL	58	1185	52	1245	41	1240	50	1223
RTXL760	57	1164	52	1238	40	1204	49	1202
Thad	60	1251	55	1347	44	1337	53	1312
Titan	62	1290	55	1335	42	1286	53	1303
Wells	60	1236	53	1284	43	1301	52	1274
Mean	59	1223	53	1272	41	1245	51	1247
$LSD_{0.05}$[b]	1.1	31.1	1.1	32.7	1.7	51.2	NS	32.4

[a] DD50 units calculated daily by the 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 University of Arkansas System Division of Agriculture's Rice Research and Extension Center, Stuttgart, Ark., during 2016.

	Thermal unit accumulations by seeding date											
	22 March		5 April		23 April		6 May		9 June		Average	
Cultivar	days	DD50[a] units	days	DD50 units	days	DD50 units	days	DD50 units	days	DD50 units	days	DD50 units
CL111	83	1922	81	1995	78	2022	75	2069	.	.	79	2002
CL151	85	1976	83	2050	78	2045	77	2127	.	.	81	2049
CL153	90	2129	86	2126	81	2132	79	2210	.	.	84	2149
CL163	84	1953	85	2103	82	2156	84	2358	.	.	84	2143
CL172	88	2068	85	2111	81	2124	80	2218	.	.	83	2130
CL272	93	2235	89	2242	83	2188	81	2258	.	.	86	2231
Diamond	89	2106	85	2095	80	2108	78	2180	.	.	83	2122
Jupiter	93	2235	91	2281	84	2226	81	2274	.	.	87	2254
LaKast	84	1945	83	2042	78	2037	73	2009	.	.	79	2008
Mermentau	90	2129	86	2133	81	2124	79	2194	.	.	84	2145
Roy J	93	2227	91	2288	85	2242	83	2321	.	.	88	2270
RT 7311 CL	81	1876	80	1965	77	1998	73	2031	.	.	78	1967
RT CLXL729	85	1976	83	2050	79	2076	78	2180	.	.	81	2070
RT CLXL745	80	1844	81	1980	77	1998	74	2047	.	.	78	1967
RT Gemini 214 CL	90	2129	86	2126	82	2156	81	2266	.	.	84	2169
RT XL753	82	1892	82	2018	78	2022	73	2031	.	.	79	1967
RT XL760	89	2113	86	2141	81	2140	82	2282	.	.	84	2169
Thad	87	2045	86	2141	84	2226	83	2314	.	.	85	2181
Titan	86	2007	84	2065	78	2037	76	2098	.	.	81	2052
Wells	89	2121	85	2118	81	2132	79	2196	.	.	84	2142
Mean	87	2046	85	2103	80	2109	78	2183	.	.	83	2111
$LSD_{0.05}$[b]	1.4	43.2	1.2	36.3	0.8	24.0	1.7	51.1	.	.	2.7	47.9

[a] DD50 units calculated daily by the 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 University of Arkansas System Division of Agriculture's Rice Research and Extension Center, Stuttgart, Ark., during 2016.

Cultivar	Grain yield by seeding date					
	22 March	5 April	23 April	6 May	9 June	Average
	(bu/acre)					
CL111	181	200	157	150	152	168
CL151	216	216	154	132	117	167
CL153	211	206	177	138	152	177
CL163	191	206	172	146	140	171
CL172	212	193	167	118	157	170
CL272	215	203	177	129	167	178
Diamond	230	225	190	159	193	200
Jupiter	219	214	208	166	172	196
LaKast	213	218	185	177	171	193
Mermentau	181	167	146	133	158	157
Roy J	195	179	179	148	168	174
RT7311CL	249	264	198	231	196	228
RTCLXL729	237	241	193	223	186	216
RTCLXL745	222	217	205	216	184	209
RT Gemini 214CL	258	235	216	232	191	227
RTXL753	247	264	204	237	193	229
RTXL760	257	233	206	231	201	225
Thad	216	218	196	145	169	189
Titan	223	228	191	169	169	196
Wells	206	185	156	134	175	171
Mean	219	216	184	171	171	192
$LSD_{0.05}$[a]	22.9	19.4	18.2	11.3	18.3	17.8

[a] LSD = least significant difference.

Table 5. Influence of seeding date on milling yield of selected rice cultivars in studies conducted at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center, Stuttgart, Ark., during 2016.

	Milling yield by seeding date					
Cultivar	22 March	5 April	23 April	6 May	9 June	Average
	----	----	----	(%HR-%TR)[a]	----	----
CL111	65-71	67-73	62-72	63-73	63-72	64-72
CL151	62-70	66-72	64-72	64-72	62-71	63-72
CL153	66-72	67-73	65-73	66-73	65-73	66-73
CL163	61-70	62-72	63-72	62-71	66-73	63-72
CL172	64-71	67-73	61-72	59-70	66-73	63-72
CL272	66-70	68-71	61-71	56-70	60-70	62-70
Diamond	57-69	61-71	58-72	59-71	64-72	60-71
Jupiter	63-68	66-69	63-69	65-70	65-69	65-69
LaKast	53-69	60-72	57-72	53-71	65-73	58-72
Mermentau	63-71	66-72	62-72	64-72	66-72	64-72
Roy J	58-70	65-73	60-72	60-71	66-74	62-72
RT7311CL	57-70	60-72	53-71	56-72	64-74	58-72
RTCLXL729	59-69	60-70	57-70	59-71	64-73	60-70
RTCLXL745	59-71	63-73	55-72	60-73	67-75	61-73
RT Gemini 214CL	58-70	61-71	59-71	62-71	65-73	61-71
RTXL753	58-71	63-73	48-70	51-72	63-74	57-72
RTXL760	58-69	61-71	58-71	62-72	65-73	61-71
Thad	61-70	65-72	61-72	63-71	64-72	63-71
Titan	62-69	67-70	60-70	53-69	62-70	61-70
Wells	58-71	63-73	58-73	59-72	63-74	60-72
Mean	61-70	64-72	59-70	60-70	64-71	62-71
%HR $LSD_{0.05}$[b]	2.08	1.4	3.4	2.8	2.0	2.2
%TR $LSD_{0.05}$[b]	0.9	0.6	0.9	0.7	0.9	0.7

[a] %HR - %TR = percent head rice – percent total white rice.

[b] LSD = least significant difference.

Late-Season Nitrogen Application to Hybrid Rice—First Year Results

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Abstract

Hybrid rice cultivars are seeded on approximately 40% of Arkansas rice acres each year. The standard practice of applying an additional 30 lb nitrogen (N)/acre to hybrid cultivars at the late-boot growth stage has been shown to minimize lodging and at times to enhance grain and milling yield. This recommendation is based on studies conducted using cultivars that are no longer being grown and it is unclear if those findings can be applied to current hybrid rice cultivars. Therefore, a study was initiated in 2016 to determine the possible benefit of a late-season boot N application made to current hybrid rice cultivars. The RiceTec hybrids, CLXL745 and XL753, were seeded at the University of Arkansas System Division of Agriculture's Northeast Research and Extension Center (NEREC), the Pine Tree Research Station (PTRS), and the Rice Research and Extension Center (RREC). There was very little response to N fertilizer at the PTRS location during 2016, likely due to a preplant poultry litter application made in response to precision leveling of the field in the winter of 2015/2016. First year results suggest that RiceTec CLXL745 may benefit from the late-boot N fertilizer application as concerns lodging and at times milling yield. RiceTec XL753 did not display any lodging in this initial study to examine the influence of the late-boot N application on lodging. However, it was observed that the late-boot N did have an influence on the milling yield of XL753 at times. The influence of the late-boot N application on the grain yield of CLXL745 and XL753 was never significant, but there was a tendency at times for the grain yield to display a numerical increase from the late-boot N application.

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Introduction

Hybrid rice cultivars are seeded on approximately 40% of Arkansas rice acres and are comprised largely of the Rice Tec hybrids CLXL745 and XL753 (Hardke, 2016). Nitrogen (N) management of these and other hybrids is very similar to currently grown pure-line varieties. The exception to this would be the standard practice of applying an additional 30 lb N/acre at the late-boot stage, termed late-boot N, after the panicle has moved fully into the boot but before the panicle begins to emerge from the leaf sheath (Norman et al., 2013). The N application at the late-boot growth stage has been shown to minimize lodging and at times to enhance grain (Norman et al., 2006, 2007, 2008) and milling yield (Walker et al., 2008). This recommendation is based on N-rate and distribution studies conducted 8 to 10 years ago on hybrid cultivars that are no longer being grown. Thus, we need to conduct N-rate studies on the current hybrid rice cultivars and see how they respond with and without the late-boot N application as concerns grain yield, milling yield, and lodging. Therefore, a study was initiated in 2016 to determine the possible benefit of the late-season boot N application commonly made to the current hybrid rice cultivars.

Procedures

The studies were conducted at the University of Arkansas System Division of Agriculture's Northeast Research and Extension Center (NEREC) near Keiser, Ark., on a Sharkey clay; at the Pine Tree Research Station (PTRS) near Colt, Ark., on a Calhoun silt loam; and at the Rice Research and Extension Center (RREC) near Stuttgart, Ark., on a DeWitt silt loam. The RiceTec hybrids, CLXL745 and XL753 were drill-seeded on the silt loams and the clay soil at an average rate of 22.5 or 27.3 lb seed/acre, respectively, in plots 9 rows (7-in. spacing) wide and 15 ft in length. Pertinent agronomic information for each location is shown in Table 1. Preflood N fertilizer was applied to a dry soil surface at the 4- to 5-lf growth stage using N-(n-butyl) thiophosphoric triamide (NBPT)-coated urea as the N source. The silt loam soils at the PTRS and RREC received 60, 90 or 120 lb N/acre and the clay soil at the NEREC received 90, 120, or 150 lb N/acre. Rice grown on clay soils generally requires 30 lb/acre more N compared to rice grown on silt loam soils. Depending on location, the studies were flooded within 1 to 4 days after N fertilizer application and remained so until the rice was mature. Just prior to beginning heading, all plots received an additional treatment consisting of either no N fertilizer or 30 lb N/acre. At maturity, the center 5 rows of each plot were harvested using a small-plot combine, the moisture content and weight of the grain were determined and a subsample removed for milling purposes. Grain yields were calculated as bu/acre at 12% moisture. A bushel (bu) of rice weighs 45 pounds (lb). The dried rice was milled to obtain percent head rice (%HR, whole kernels) and percent total white rice (%TR) to provide a milling yield expressed as %HR and %TR. At the three locations, each hybrid was arranged as a randomized complete block with four replications. Statistical analyses were conducted with SAS 9.4 (SAS Institute Inc., Cary, N.C.) and means were separated using Fisher's protected least significant difference test ($P = 0.05$) where appropriate.

Results and Discussion

For the rice hybrid CLXL745 during 2016, grain yield at the NEREC was greater when the preflood nitrogen (N) rate increased from 90 to 120 lb N/acre, but was similar when the N rate increased from 120 to 150 lb N/acre (Table 2). Grain yield increased from 211 to 224 bu/acre when the N rate increased from 90 to 120 lb N/acre, but only increased to 225 bu/acre when the preflood N rate increased from 120 to 150 lb N/acre. Incremental increases in preflood N from 60 to 90 to 120 lb N/acre did not influence grain yield at the PTRS during 2016. An application of 1 ton/acre of poultry litter made prior to spring planting, because of precision leveling of the field during the winter months, was probably the reason for this lack of N fertilizer response. Average grain yield at this location was 206 bu/acre and differed by only 2 bu/acre across the 3 preflood N application rates. At the RREC, grain yield significantly increased as N rate increased from 60 to 90 lb N/acre and from 90 to 120 lb N/acre, achieving a maximum yield of 185 bu/acre.

The additional application of urea at the late-boot growth stage did not significantly influence the grain yield of CLXL745 during 2016 at any of the three locations (Table 3). There was a general trend of greater grain yield with the boot N application with two of the preflood N rates at the NEREC and RREC, but only for one of the preflood N rates at the PTRS. As noted above, any potential grain yield response to additional N applications made at the PTRS could have been influenced by the poultry litter application. Although boot N fertilizer application did not significantly increase grain yield at the NEREC compared to no boot N fertilizer, there was a noted decrease in lodging with the additional application of 30 lb N/acre for rice receiving the highest preflood N rate of 150 lb N/acre. At the PTRS, lodging tended to be lower with additional boot N fertilizer compared to no additional boot N at each of the three levels of preflood N. There was no lodging noted in this cultivar at the RREC during 2016.

Preflood N also influenced the milling yield of CLXL745 during 2016 (Table 4). Percent head rice increased as preflood N rate increased from 90 to 150 lb N/acre at the NEREC. Percent total white rice increased as N rate increased from 90 to 120 lb N/acre but was similar as N rate increased from 120 to 150 lb N/acre at the NEREC. Contrary to the grain yield results at the PTRS, %HR increased significantly as preflood N rate increased from 60 to 90 or 60 to 120 lb N/acre, and increased numerically as the preflood N rate increased from 90 to 120 lb N/acre. Percent total white rice also tended to increase as N rate increased but was only significant as N rate increased from 60 to 120 lb N/acre at the PTRS. It is somewhat surprising that the milling yield of CLXL745 was influenced by preflood N when the grain yield was not due to the application of the poultry litter. At the RREC, %HR increased incrementally as N rate increased and reached a maximum of 60.0% when 120 lb N/acre was applied. Percent total white rice tended to increase as preflood N rate increased from 60 to 120 lb N/acre, but was only significant from 60 to 90 or 60 to 120 lb N/acre at the RREC.

Application of boot N to CLXL745, averaged across preflood N rates, tended to increase %HR and %TR at all locations during 2016 (Table 5). However, %HR was statistically higher with the boot N only at RREC; whereas %TR was higher with the boot N at both NEREC and RREC. Somewhat similar to the grain yield results, application of boot N had no influence on milling yield at the PTRS during this study year. The lack of milling yield response to late-boot N fertilizer, even for rice receiving a suboptimum preflood N rate of 60 lb N/acre at the PTRS, coupled with the lack of response to N fertilizer in general, again suggests the influence of the spring-applied poultry litter at this location.

Grain yield of XL753, on the clay soil at the NEREC, increased to a maximum of 240 bu/acre as the preflood N rate increased from 90 to 150 lb N/acre (Table 6). At the PTRS, the highest N rate of 120 lb N/acre contributed to a maximum grain yield of 219 bu/acre, but there was no significant preflood N response for this cultivar due probably to the preplant application of the poultry litter to this precision graded field. Grain yield at the RREC increased from 179 to 198 bu/acre when preflood N increased from 60 to 90 lb N/acre, but remained stable at 201 bu/acre as N rate increased from 90 to 120 lb N/acre.

There was no significant grain yield response to the application of boot N fertilizer at any preflood N rate at any of the three locations during 2016 (Table 7). In general, grain yield tended to increase with the addition of a boot N application, but surprisingly usually only at the two highest preflood N rates. There was no lodging of XL753 during 2016 at any of the three locations. Therefore, we were unable to evaluate any effect the boot N application may have had on lodging of this cultivar.

Preflood N positively influenced the milling yield of XL753 during 2016 (Table 8). At all locations, both %HR and %TR tended to increase as N rate increased. At the NEREC, %HR and %TR increased incrementally as N rate increased incrementally from 90 to 150 lb N/acre. At the PTRS, %HR increased significantly as N rate increased from 60 to 90, but the increase was slightly less than significant as the N rate increased from 90 to 120 lb N/acre. Also at this location, %TR displayed a nonsignificant increase as the N rate increased. At the RREC, %HR and %TR increased with each incremental increase in N fertilizer from 60 to 120 lb N/acre. The highest N rate applied at a location during 2016 resulted in maximum milling yield for that location, even at the PTRS where the ton/acre of poultry litter was applied preplant.

The late-boot N application made to XL753, averaged across preflood N rates, tended to increase %HR at all locations during 2016, but the increase was significant only at the RREC (Table 9). Percent total white rice showed a nonsignificant 0.5% increase at the NEREC when boot N was applied, but %TR displayed a 2.2% nonsignificant decrease when boot N was applied at the PTRS. Both %HR and %TR increased significantly at the RREC with the application of late-boot N compared to rice not receiving boot N.

Significance of Findings

Results from this initial study suggest that RiceTec CLXL745 may benefit from the late-boot N fertilizer application as concerns lodging and at times milling yield. RiceTec XL753 did not display any lodging in this initial study to examine the influence of the late-boot N application on lodging. However, it was observed that the late-boot N did have an influence on the milling yield of XL753 at times. The influence of the late-boot N application on the grain yield of CLXL745 and XL753 was never significant, but there was a tendency at times for the grain yield to display a numerical increase from the late-boot N application. Data collected in additional growing seasons will be useful in making a more sound and clear determination on the influence of the late-boot N application on lodging, milling yield and grain yield of these two hybrids.

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Table 1. Pertinent agronomic information for the University of Arkansas System Division of Agriculture's Northeast Research and Extension Center (NEREC), Pine Tree Research Station (PTRS), and the Rice Research and Extension Center (RREC) during 2016.

Practices	NEREC	PTRS	RREC
Preplant fertilizer	----	----	60 lb P_2O5/acre 90 lb K_2O/acre + 10 lb Zn/acre
Herbicide spray dates and spray procedures	1 April 32 oz RoundUp		
Planting dates	25 April	11 May	5 May
Herbicide spray dates and spray procedures	25 April 40 oz/acre Facet L + 1.4 pt/acre Command + 0.75 oz/acre Permit Plus	17 May 2.1 pt/acre Prowl + 3.2 oz/acre League	6 May 8 oz/acre Command + 20 oz/acre Facet L
Emergence dates	5/11	5/19	5/12
Herbicide spray dates and spray procedures	9 June 4 qt/acre Propanil	3 June 3 qt/acre Propanil	----
Preflood N dates	10 June	15 June	9 June
Flood dates	12 June	19 June	10 June
Boot N application	27 July	28 July	July 21
Insecticide spray dates and spray procedures	----	----	15 July 2.5 oz/acre Karate
Drain dates	26 August	8 September	31 August
Harvest dates	14 September	29 September	7 September

Table 2. Influence of preflood nitrogen (N) fertilizer rate on the grain yield of RiceTec CLXL745 hybrid rice at three locations during 2016.

	Grain yield		
PF N Rate	NEREC†	PTRS‡	RREC
(lb N/acre)	(bu/acre)		
60	----	207 [13§]	150 c¶
90	211 b	205 [15]	167 b
120	224 a[3]	206 [20]	185 a
150	225 a[28]	----	----
$LSD_{0.05}$#	12.2	NS ††	10.7

† NEREC = Northeast Research and Extension Center, Keiser, Ark.; PTRS = Pine Tree Research Station, Colt, Ark.; RREC = Rice Research and Extension Center, Stuttgart, Ark.
‡ PTRS received winter-applied poultry litter which probably impacted the response to fertilizer N.
§ Number in superscript to the side of the grain yield are lodging percentages.
¶ Means followed by the same letter within a column are not statistically different ($P < 0.05$).
# LSD = least significant difference.
†† NS = not significant.

Table 3. Influence of preflood nitrogen (N) fertilizer rate and late-boot N application on the grain yield of RiceTec CLXL745 hybrid rice at three locations during 2016.

	Grain yield					
	Location/ boot N rate (lb N/acre)					
	NEREC†		PTRS‡		RREC	
PF N Rate	0	30	0	30	0	30
(lb N/acre)	(bu/acre)					
60	----	----	207 [18§]	206 [8]	153	148
90	207	215	202 [25]	208 [5]	162	171
120	220 [3]	228 [3]	207 [23]	206 [18]	181	189
150	225 [38]	226 [17]	----	----	----	----
$LSD_{0.05}$¶	NS#		NS		NS	

† NEREC = Northeast Research and Extension Center, Keiser, Ark.; PTRS = Pine Tree Research Station, near Colt, Ark.; RREC = Rice Research and Extension Center, Stuttgart, Ark.
‡ PTRS received winter-applied poultry litter which probably impacted the response to fertilizer N.
§ Number in superscript to the side of the grain yield are lodging percentages.
¶ LSD = least significant difference.
# NS = not significant.

Table 4. Influence of preflood nitrogen (N) fertilizer rate on the milling yield of RiceTec CLXL745 hybrid rice at three locations during 2016.

	Milling Yield		
PF N Rate	**NEREC[†]**	**PTRS[‡]**	**RREC**
(lb N/acre)	----------------------------	**(%HR-%TR[§])**	----------------------------
60	----	38.7-68.1	51.8-70.5
90	57.2-72.1	45.9-69.3	56.9-71.9
120	61.6-73.2	50.1-70.3	60.0-72.5
150	63.1-73.4	----	----
%HR $LSD_{0.05}$[¶]	1.4	5.0	2.1
%TR $LSD_{0.05}$	0.4	1.4	0.7

[†] NEREC = Northeast Research and Extension Center, Keiser, Ark.; PTRS = Pine Tree Research Station, near Colt, Ark.; RREC = Rice Research and Extension Center, Stuttgart, Ark.
[‡] PTRS received winter-applied poultry litter which probably impacted the response to fertilizer N.
[§] %HR-%TR = % head rice and % total white rice.
[¶] LSD = least significant difference.

Table 5. Influence of nitrogen (N) fertilizer at the late-boot growth stage on the milling yield of RiceTec CLXL745 hybrid rice at three locations during 2016.

	Milling yield		
Boot N Rate	**NEREC[†]**	**PTRS[‡]**	**RREC**
(lb N/acre)	----------------------------	**(%HR-%TR[§])**	----------------------------
0	60.2-72.7	44.2-68.9	54.8-71.2
30	61.0-73.1	45.6-69.6	57.7-72.1
%HR $LSD_{0.05}$[¶]	NS[#]	NS	1.7
%TR $LSD_{0.05}$	0.4	NS	0.5

[†] NEREC = Northeast Research and Extension Center, Keiser, AR; PTRS = Pine Tree Research Station, Colt, AR; RREC = Rice Research and Extension Center, Stuttgart, AR.
[‡] PTRS received winter-applied poultry litter which probably impacted the response to fertilizer N.
[§] %HR-%TR = % head rice and % total white rice.
[¶] LSD = least significant difference.
[#] NS = not significant.

Table 6. Influence of preflood nitrogen (N) fertilizer rate on the grain yield of RiceTec XL753 hybrid rice at three locations during 2016.

	Grain yield		
PF N Rate	NEREC[†]	PTRS[‡]	RREC
(lb N/acre)	(bu/acre)		
60	----	214	179 b[§]
90	209 c	214	198 a
120	226 b	219	201 a
150	240 a	----	----
$LSD_{0.05}$[¶]	12.8	NS	11.4

[†] NEREC = Northeast Research and Extension Center, Keiser, Ark.; PTRS = Pine Tree Research Station, near Colt, Ark.; RREC = Rice Research and Extension Center, Stuttgart, Ark.
[‡] PTRS received winter-applied poultry litter which probably impacted the response to fertilizer N.
[§] Means followed by the same letter within a column are not statistically different (P < 0.05).
[¶] LSD = least significant difference.

Table 7. Influence of preflood nitrogen (N) fertilizer rate and late-boot N application on the grain yield of RiceTec XL753 hybrid rice at three locations during 2016.

	Grain yield					
	Location/ boot N rate (lb N/acre)					
	NEREC[†]		PTRS[‡]		RREC	
PF N Rate	0	30	0	30	0	30
(lb N/acre)	(bu/acre)					
60	----	----	213	215	179	178
90	210	207	209	218	196	201
120	223	230	218	220	197	206
150	235	246	----	----	----	----
$LSD_{0.05}$[§]	NS[¶]		NS		NS	

[†] NEREC = Northeast Research and Extension Center, Keiser, Ark.; PTRS = Pine Tree Research Station, near Colt, Ark.; RREC = Rice Research and Extension Center, Stuttgart, Ark.
[‡] PTRS received winter-applied poultry litter which probably impacted the response to fertilizer N.
[§] LSD = least significant difference.
[¶] NS = not significant.

Table 8. Influence of preflood nitrogen (N) fertilizer rate on the milling yield of RiceTec XL753 hybrid rice at three locations during 2016.

	Milling yield		
Boot N Rate	NEREC[†]	PTRS[‡]	RREC
(lb N/acre)	----------------------------	(%HR-%TR[§])	----------------------------
60	----	26.3-62.1	44.7-70.1
90	35.8-69.1	31.9-67.0	49.3-71.2
120	44.9-70.7	34.8-68.0	55.0-72.2
150	50.9-72.1	----	----
%HR $LSD_{0.05}$[¶]	4.5	3.1	2.2
%TR $LSD_{0.05}$	0.9	NS[#]	0.6

[†] NEREC = Northeast Research and Extension Center, Keiser, Ark.; PTRS = Pine Tree Research Station, near Colt, Ark.; RREC = Rice Research and Extension Center, Stuttgart, Ark.
[‡] PTRS received winter-applied poultry litter which probably impacted the response to fertilizer N.
[§] %HR-%TR = % head rice and % total white rice.
[¶] LSD = least significant difference.
[#] NS = not significant.

Table 9. Influence of nitrogen (N) fertilizer at the late-boot growth stage on the milling yield of RiceTec XL753 hybrid rice at three locations during 2016.

	Milling yield		
Boot N Rate	NEREC[†]	PTRS[‡]	RREC
(lb N/acre)	----------------------------	(%HR - %TR[§])	----------------------------
0	42.3-70.4	29.8-66.8	48.4-70.9
30	45.4-70.9	32.2-64.6	50.9-71.4
%HR $LSD_{0.05}$[¶]	NS[#]	NS	1.8
%TR $LSD_{0.05}$	NS	NS	0.5

[†] NEREC = Northeast Research and Extension Center, Keiser, Ark.; PTRS = Pine Tree Research Station, near Colt, Ark.; RREC = Rice Research and Extension Center, Stuttgart, Ark.
[‡] PTRS received winter-applied poultry litter which probably impacted the response to fertilizer N.
[§] %HR-%TR = % head rice and % total white rice.
[¶] LSD = least significant difference.
[#] 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. Occasionally, questions arise concerning the presence of muddy or flooded field conditions in the recommended window for preflood N fertilizer application. A study was conducted in 2016 to determine the best management strategy for applying N fertilizer in fields where weather conditions prevent optimum timing of N application to dry soil conditions. Treatments included: recommended single preflood (SPF) applied to dry soil; recommended two-way split with the preflood N applied to dry soil (2WS-dry); the 2WS with preflood N applied to wet soil (2WS-wet); an enhanced 2WS with an additional 25 lb N/acre applied preflood to wet soil (E2WS-wet); variations of sequential fertilizer applications into the floodwater; and a no N fertilizer check. Nitrogen fertilizer applications were initiated based on dates noted from a report generated in the Degree-Day 50 (DD50) Rice Management Program. There were several application timings initiated after establishment of the permanent flood that resulted in grain yields similar to the two recommended practices, SPF or 2WS-dry. However, each of these require an additional 30 to 95 lb N/acre and 2 to 4 additional applications compared to the recommended SPF or 2WS-dry fertilizer applications.

Introduction

Approximately 96% of Arkansas rice is grown using the dry-seeded, delayed-flood system (Hardke, 2016). In this system, 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

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(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 46 lb N/acre applied after the rice has begun reproductive growth. The timing of the second application, termed midseason N, is based on meeting two requirements: (1) the permanent flood must have been established a minimum of 21 days and (2) the rice should have begun reproductive growth (i.e. beginning internode elongation). The SPF and 2WS options are based on field conditions such as the timeliness of flood establishment after the preflood N has been applied and the ability to maintain an adequate flood after establishment for a minimum of 3 weeks. Also, establishing a permanent flood serves two purposes: (1) the urea or ammonium fertilizer is moved into the soil profile with the wetting front to minimize ammonia volatilization and place the N fertilizer 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 via nitrification/denitrification processes.

Occasionally, questions arise concerning the presence of muddy or flooded field conditions in the recommended window for preflood N fertilizer application. A study was conducted in 2016 to determine the best management strategy for applying N fertilizer in fields where weather conditions prevent optimum timing of N application to dry soil conditions.

Procedures

During 2016, the study was located 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 LaKast rice drill-seeded at a rate of 70 lb seed/acre (30 seed/ft^2) in plots 9 rows (7-in. spacing) wide and 15 ft in length. The study followed soybean in rotation. The study was seeded on 6 May, emerged 14 May and the permanent flood established 8 June. Cultural management practices used were standard to the dry-seeded, delayed-flood production system. Treatments included: recommended single preflood N (SPF) applied to dry soil; recommended two-way split with the preflood N applied to dry soil (2WS-dry); the 2WS with preflood N applied to wet soil (2WS-wet); an enhanced 2WS with an additional 25 lb N/acre applied preflood to wet soil (E2WS-wet); variations of sequential fertilizer applications into the floodwater; and a no N fertilizer check (Table 1). Urea coated with N-(n-butyl) thiophosphoric triamide (NBPT) urea was used for treatments where preflood N fertilizer was applied to dry or muddy soil. Untreated urea was used for all N applications into the floodwater. Selected fertilizer application timing/frequency combinations were not carried forward from the 2015 study (Frizzell et al., 2016) due to lack of grain yield response or reduced economic returns. Additional application timings were incorporated into the 2016 study to further address grower concerns.

A portable rainfall simulator (6.0-ft wide × 15.0-ft long × 2.5-ft tall) was constructed to simulate a rainfall event to create muddy soil conditions at the time of selected preflood N applications. The sides of the PVC frame were covered with a removable tarp to reduce water movement due to wind. A greenhouse rainfall nozzle attached to a 25-gal tank using 0.5-in. diameter garden hose, was used to evenly distribute 14 gal of water within the rainfall simulator (90 ft^2). The nozzle was held approximately 30-in. from the soil surface. The simulated rainfall event of 0.25-in. occurred approximately 30 minutes prior to preflood N application. The lapse in time was needed to insure the absence of standing water in the area to be fertilized.

Nitrogen fertilizer applications were initiated based on dates noted from a report generated in the Degree-Day 50 (DD50) Rice Management Program. Preflood N fertilizer applications were made on 7 June to either the recommended dry soil surface or a muddy soil surface. Fertilizer applications made solely into the floodwater were initiated 1, 7 or 14 d following permanent flood establishment. Timing of the applications initiated 7 d after permanent flood establishment corresponded to the final recommended date to apply preflood N as determined by heat unit accumulation in the DD50 program. The application initiated 14 days following permanent flood establishment corresponded to 7 days after the final recommended date to apply preflood N according to the DD50 program. Midseason N was applied 1 July after LaKast had begun reproductive growth, which corresponds to 23 days after permanent flood establishment. All plots receiving N in the floodwater, either solely or at midseason, were surrounded by a galvanized metal frame that rested on the soil surface and allowed water movement into the plot area. This was done prior to N fertilizer application to reduce potential movement of fertilizer into surrounding plots. The study was arranged as a randomized complete block and treatment means were separated using Fisher's protected least significant difference test with $P = 0.05$.

Results and Discussion

During 2016, grain yield was positively influenced by N application compared to no additional fertilizer N, but was somewhat similar between application timings (Table 1). A maximum grain yield of 188 bu/acre was achieved when fertilizer was applied using the standard 2WS-dry recommendation for this variety and soil type. In addition, the 2WS-dry application timing resulted in increased grain yield compared to preflood N application being made to a wet soil surface as in the 2WS-wet and the E2WS-wet which is consistent with previous research. It was hypothesized that increasing the preflood N rate applied to wet soil would compensate for potential N losses that might negatively influence grain yield; however, these results do not support that hypothesis. Although grain yield comparison between 2WS-wet (105 lb N/acre preflood) and E2WS-wet (130 lb N/acre N preflood) are statistically similar, there is a numeric difference of 12 bu/acre between the two treatments. The recommended practice of applying N fertilizer as a SPF application onto dry soil just prior to permanent flood establishment also resulted in a grain yield statistically similar to the 2WS-dry timing, although there was a numerical difference of 11 bu/acre between the two treatments. There were several application timings initiated after establishment of the permanent flood that resulted in grain yield similar to the two recommended practices during 2016. However, each of these require an additional 30-95 lb N/acre and 2-4 additional applications compared to the recommended SPF or 2WS-dry fertilizer applications.

Of the N application timings initiated into the floodwater, the Flood Initiation timing (5 applications of 46 lbs N/acre every 7 d beginning 1 day after flood establishment) tended toward lower grain yield than the three timings beginning at, or 7 days after, the final recommended date to apply preflood N. In this same study conducted in 2015, the Flood Initiation N application timing resulted in the lowest grain yield of any of the N timings studied (Frizzell et al., 2016).

Grain harvest was planned for 19 September, but a rain event coupled with heavy winds delayed harvest until 21 September. Lodging due to this weather event likely increased the variability in grain yield results observed during 2016. Lodging varied between treatments, but preflood N fertilizer application to dry soil conditions tended toward lower percent lodging compared to rice receiving N applications onto wet soil conditions, or into the floodwater.

Significance of Findings

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

Acknowledgments

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Table 1. Influence of nitrogen (N) fertilizer application timing on the grain yield and lodging of LaKast rice at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center near Stuttgart, Ark., during 2016.

Treatment no.	N Timing	N Application Frequency[†]	Rate	Total N fertilizer Applied	Grain yield	Lodging
			----- (lb N/acre) -----		(bu/acre)	(%)
1	Control	none	0	0	108 e[‡]	0 b
2	SPF	PF	130	130	177 abc	0 b
3	2WS dry[§]	PF fb MS	105 fb 46	150	188 a	8 b
4	2WS wet[§]	PF fb MS	105 fb 46	150	169 bcd	45 a
5	E2WS wet[§]	PF fb MS	130 fb 46	175	157 d	49 a
6	Flood initiation[¶]	7-8d intervals	5 x 46[#]	225	165 cd	46 a
7	Final DD50[††]	7-8d intervals	4 x 46	180	173 abcd	18 ab
8	Final DD50	7-8d intervals	5 x 46	225	184 ab	45 a
9	Final DD50 +7d	7-8d intervals	5 x 46	225	176 abc	23 ab
$LSD_{0.05}$[‡‡]					17.0	36.8

[†] PF = preflood, fb = followed by, and MS = midseason.
[‡] Means followed by the same letter are not significantly different (*P* = 0.05).
[§] Preflood N applied to "dry" or "wet" (muddy) soil surface just prior to flooding.
[¶] One day postflood (9 June - two days after initial recommended date to apply preflood N fertilizer when rice has reached 4- to 5-lf growth stage based on Degree-Day 50 (DD50) Rice Management Program).
[#] 5 x 46 represents 5 applications of 46 lb N/acre at each application.
[††] Final DD50 = Final recommended date to apply preflood N fertilizer (16 June for this trial) based on DD50 Rice Management Program.
[‡‡] LSD = least significant difference.

Investigation of Soil Properties Influencing Hydrogen Sulfide Toxicity

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Abstract

Hydrogen sulfide toxicity (HST) is a poorly understood phenomenon that occurs under anaerobic conditions and can be problematic in rice (*Oryza sativa* L.) fields. Though the presence of this disorder is inconsistent from year to year and field to field, HST can cause significant yield loss when it occurs. Excessive sulfur and the reduction of sulfate to hydrogen sulfide is thought to be the main cause of HST, though it is becoming apparent that there are many other factors that influence the occurrence of HST in Arkansas. A greenhouse study was designed to investigate the differences in four soils in Arkansas where this disorder has regularly appeared: Hunter (H) and Hickory Ridge west (HR-W); sometimes appeared: Hickory Ridge east (HR-E); and has never been reported: the University of Arkansas System Division of Agriculture's Pine Tree Research Station (PTRS). This greenhouse study examined the sulfate concentrations in solution and redox potential over time in an anaerobic environment with both sterile and unsterile soil. Soil test results for these four soils indicated differences in sulfate and iron concentration as well as the percentage of silt. During the course of the greenhouse trial, there was a significant difference in sulfate concentration between sterilization treatments from day 7 to day 77. This difference indicates that microbes highly influence the amount and rate sulfate is reduced to sulfide. There was also a significant difference between locations from day 21 to day 77; however H and PTRS were not statistically different. Redox potential did drop more rapidly in H than PTRS. This suggests that redox potential greatly influences the occurrence of HST, despite the amount of sulfate being reduced. Results from this study indicate that there are many influential factors in the occurrence of HST.

Introduction

Rice is a widely grown crop in eastern Arkansas and is a staple of Arkansas's economy, contributing over 6 million dollars annually. Producers are faced with many

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challenges throughout the growing season including problems associated with soil disorders. One of these is hydrogen sulfide toxicity (HST), a poorly understood soil disorder. Symptoms of HST appear approximately 2 weeks after the permanent flood has been established, and symptoms include wilting, yellowing, stunting, and the blackening of the roots (Wamishe et al., 2013). Hydrogen sulfide toxicity weakens the rice plant by preventing the roots from taking up water and nutrients (Tanaka and Yoshida, 1966; Ou, 1985). Once weakened, opportunistic fungi often invade and kill the plant (Tanaka and Yoshida, 1966). Currently, the only way to address this problem is by temporarily draining the field to reintroduce oxygen to the root zone until new root growth occurs (Wamishe et al., 2013).

Hydrogen sulfide toxicity is suspected to be caused by excessive sulfur in the root zone which is reduced under flooded conditions to hydrogen sulfide—a toxic gas (Hardke and Wamishe, 2015). Originally identified in Japan, this disorder was seen in two different soil conditions: well-drained, sandy, degraded paddy soils and poorly drained paddy soils with plentiful organic matter (Baba et al., 1965). However, in Arkansas this disorder has appeared in fields from silt loam to clay loam textures (Wamishe, 2012).

The disorder is driven by chemical transformations occurring in anaerobic conditions. Understanding redox potential (Eh) is key to understanding these chemical transformations in anaerobic soils. Redox potential measures the tendency of chemical species in solution to be transformed. This transformation is typically performed by microbial respiration, though redox can change abiotically (Strawn et al., 2015). Though there is debate over the exact Eh where sulfate becomes the primary terminal electron acceptor for microbes, sulfate reduction generally occurs at -100 mV (Harter and McLean, 1965). Understanding the chemistry of anaerobic soils is a key component in understanding this disorder. The objectives of this research were to evaluate the importance of microbes in redox reactions and to identify the potential chemical and physical characteristics between soils prone to HST compared to soils with no history of this disorder.

Procedures

A greenhouse experiment was conducted at the University of Arkansas System Division of Agriculture's Agricultural Experiment Station in Fayetteville, Ark., to evaluate physical and chemical characteristics of various soils in Arkansas. Soils were collected from three locations: Hunter (H), Ark.; Hickory Ridge (HR), Ark.; and the University of Arkansas System Division of Agriculture's Pine Tree Research Station (PTRS) near Colt, Ark. Soils were classified based on the history of HST occurrence. Soil from H represents soil where HST always occurs when planted to rice. Two separate soils were collected from the field in HR. Soil from the west end of the field (HR-W) represents another soil where HST always occurs, and soil from the east end of the field (HR-E) represents where this disorder occurs approximately half of the time. Soil from PTRS was collected representing soil where there has never been a report of HST.

Prior to the greenhouse trial, 4 gal of soil from each location were steam sterilized for 1 hour using an autoclave. Soils were sterilized 3 times to maximize sterilization. After sterilization, 4 gal of unsterile soil and 4 gal of sterile soil from each location were divided into 2-gal buckets, with 1 gal per bucket, giving a total of 32 buckets. Sixteen platinum electrode redox sensors (Sensorex® electrochemical ORP sensors) were placed in two replications of each location and porous ceramic cup samples (IRROMETER® Soil Solution Access Tube – Model SSAT, Riverside, Calif.) were placed in each bucket to extract soil solution. Each bucket was then flooded to approximately 4 in. above the soil surface with deionized water. This flood depth was maintained for the duration of the experiment. Redox potential was measured continuously and soil solution samples were extracted on days 1, 2, 7, 14, 21, 28, 35, 42, 49, 63, 77, and 91 after flooding and analyzed for sulfate using an inductively coupled argon plasma spectrophotometer. The experiment was terminated after 91 days. Sulfate concentrations in solution were compared across locations and sterilization treatments by day using JMP Pro 12 using Student's *t*-test at the $P = 0.05$ level.

Results and Discussion

The preliminary soil-test results indicated a few notable differences between the soils (Table 1). As hypothesized, locations where HST has occurred had higher concentrations of sulfur. We also discovered that soils from H, HR-E, and HR-W contain nearly 30% more silt than the soil from PTRS. Based on these findings, sulfur content and amount of silt in soil composition may be associated with soils that have history of HST.

Although H and PTRS soils were not significantly different in concentrations of sulfate over time, there were significant differences between locations from sampling day 21 through day 77. Redox potential (Eh) declined much more rapidly in the H soil than the PTRS soil suggesting the likelihood of sulfate serving as the terminal electron acceptor for microorganisms sooner in the H soil than it did in the PTRS soil (Harter and McLean, 1965). This may also be due to the higher content of total iron in the PTRS soil which was 73 ppm more than the H soil (Table 1). Moreover, no difference does not necessarily mean that sulfate is being reduced to hydrogen sulfide at the same rate in both soils. It is possible that the sulfate could be reduced to different forms of sulfides (Strawn et al., 2015).

The majority of the sulfate loss was detected by day 28 for all four soils (Fig. 1). Since symptoms of HST could start approximately 2 weeks after flooding, the depletion of sulfate is similar in time with the appearance of symptomology (Hardke et al., 2015). After flooding, soils from all locations experienced a steady decline in Eh and reached -100 mV between 2 and 4 weeks after flooding then eventually leveled out around -300 mV (Fig. 2).

From days 7 through day 77, sulfate concentration was significantly greater in sterile soils than unsterile soils with *P*-values ranging from 0.0231 to <0.0001. However, we believe that sterilization was not completely successful at eliminating all microbes for several reasons. First, biological respiration influences redox potential the most (Strawn et al., 2015), yet our sterile soils still experienced a change in Eh comparable to the unsterile soils (Fig. 2). Second, sulfate concentration decreased over time which suggested the presence of sulfate-reducing microbes (Fig. 1). Third, several of the buckets containing sterile soil had weeds that may have grown from seeds indicating ineffective sterilization. Regardless of these situations, our data and the slower decline in redox and sulfate concentration suggests the production of hydrogen sulfide is greatly influenced by microorganisms. Though all of the locations experienced rapid declines in Eh and sulfate concentrations, the study was indicative of a myriad of factors that influence the reduction of sulfate to hydrogen sulfide.

Significance of Findings

While there are still many questions as to why HST occurs in some fields and not in others and why it does not always occur consistently from year to year, we have discovered that this is a complicated and multileveled disorder. The reduction of sulfate to hydrogen sulfide depends on many factors including initial concentration of sulfate and ferrous iron, redox potential, and microbial activity. Future research aims at further understanding the chemistry behind this disorder as well as investigating how prone soils react to the addition of ammonium sulfate fertilizer.

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Table 1. Selected soil chemical and physical properties from Hickory Ridge West (HR-W), Hickory Ridge East (HR-E), Hunter (H), and Pine Tree Research Station (PTRS) used in the greenhouse experiment.

Location	County	Soil series	Soil classification	Soil texture[a] Sand	Silt	Clay	pH[b]	LOI[c]	TN[d]	TC[d]	P[e]	K[e]	S[e]	Fe[e]
				(%)				(%)			(ppm)			
HR-W	Cross	Henry silt loam	Coarse-silty, mixed, active, thermic, Typic Fragiaqualf	6	79	15	8.1	2.69	0.126	1.37	24	71	14	425
HR-E	Cross	Henry silt loam	Coarse-silty, mixed, active, thermic Typic Fragiaqualfs	12	74	14	8.1	2.03	0.066	0.943	19	46	10	402
H	Woodruff	Hillemann	Albic Glossic Natraqualfs	14	73	13	7.9	2.01	0.068	0.943	16	53	16	390
PTRS	St. Francis	Calloway	Aquic Fraglossudalfs	35	48	17	7.6	2.08	0.081	0.913	70	114	9	463

[a] Soil texture determined by hydrometer method (Gavlak et al., 2003).
[b] pH determined by 1:2 soil/water ratio (Thomas, 1996).
[c] Loss on ignition (LOI) determined by muffle furnace 360 °C (Combs and Nathan, 1998)
[d] Total Nitrogen (TN) and Total Carbon (TC) determined by combustion (Bermner, 1996; Nelson and Sommers, 1996).
[e] Phosphorus (P), Potassium (K), Sulfur (S), and total Iron (Fe) determined by Mehlich-3 extractable (1:10 ratio) analysis by Spectro Arcos ICP (Helmke and Sparks, 1996).

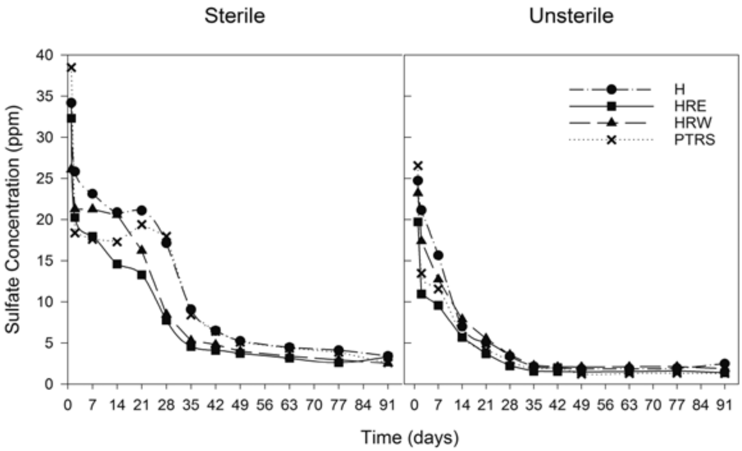

Fig. 1. Sulfate concentration of the sterile and unsterile soils over time for the duration of flooding for Hickory Ridge East (HR-E), Hickory Ridge West (HR-W), Hunter (H), and Pine Tree Research Station (PTRS).

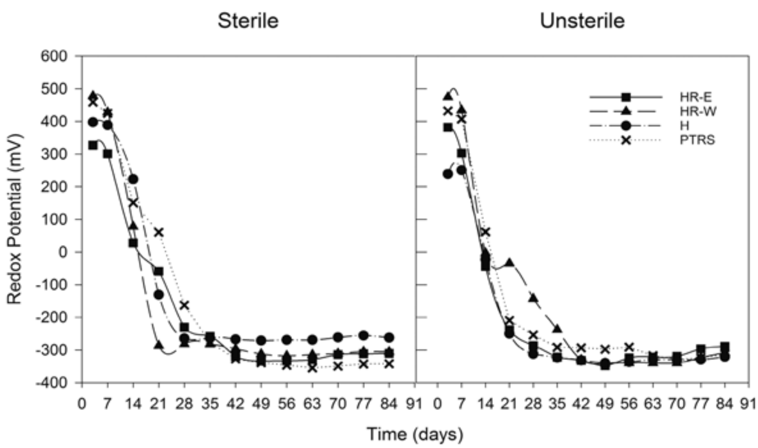

Fig. 2. Redox potential of the sterile and unsterile soils over time for the duration of flooding for Hickory Ridge East (HR-E), Hickory Ridge West (HR-W), Hunter (H), and Pine Tree Research Station (PTRS).

Arkansas Rice Performance Trials, 2014-2016

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Abstract

The Arkansas Rice Performance Trials (ARPTs) are conducted each year to evaluate promising experimental lines from the Arkansas rice breeding program and commercially available cultivars from public and private breeding programs. The ARPTs are planted on experiment stations and cooperating producer's fields in a diverse range of environments, soil types, and agronomic and pest conditions. The ARPTs were conducted at five locations during 2016. Averaged across locations, grain yields were highest for the commercial cultivars RTXL753, RTXL760, Diamond, and Titan. Cultivars with the highest overall milling yields during 2016 included: Mermentau, CL151, CL111, 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 (ARPTs) are conducted each year to compare promising new experimental lines and newly released cultivars from the breeding programs in Arkansas, Louisiana, Texas, Mississippi and Missouri with established cultivars currently grown in Arkansas. Multiple locations each year allow for continued reassessment of the performance and adaptability of advanced breeding lines and commercially available cultivars to such factors as environmental conditions, soil properties, and management practices.

Procedures

The five locations for the 2016 ARPTs included the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC) near Stuttgart, Ark.; the Pine Tree Research Station (PTRS) near Colt, Ark.; the Northeast Research and Extension Center (NEREC) near Keiser, Ark; the Newport Extension Center (NEC) near Newport, Ark.; and the Trey Bowers farm in Clay County (CLAY). Seventy-five entries, including established cultivars and promising breeding lines, were grown across a range of maturities.

The studies were seeded at RREC, PTRS, NEREC, CLAY, and NEC on 5 April, 11 May, 25 April, 13 April, and 23 May, respectively. Pure-line cultivars (varieties) were drill-seeded at a rate of 30 seed/ft^2 (loam soil) or 36 seed/ft^2 (clay soil) in plots 9 rows (7-in. spacing) wide and 15 ft in length. Hybrid cultivars were drill-seeded into the same plot configuration using a seeding rate of 10.3 seed/ft^2 (loam soil) or 12.4 seed/ft^2 (clay soil). 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 (N) fertilizer was applied to ARPT studies located on experiment stations at the 4- to 5-lf growth stage in a single pre-flood application of 130 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 established 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 (whole kernels) and percent total white rice (%HR and %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 2014-2016 are listed in Table 1. The top yielding entries, averaged across three study years, include: RiceTec (RT) XL753, RTXL760, Diamond, and Titan with grain yields of 234, 206, 197, and 197 bu/acre, respectively. In regard to percent head rice and percent total white rice (%HR and %TR), Mermentau, CL151, CL111, CL163, and Roy J had the highest overall average milling yields from 2014-2016.

Selected agronomic traits, grain yield, and milling yields from the 2016 ARPT are shown in Table 2. Grain yield averaged across all locations and cultivars was 178 bu/acre. The cultivar RTXL753 was the only commercial cultivar to maintain a grain yield above 200 bu/acre at all locations. Other notable cultivars in 2016 included RT Gemini 214CL, RT7311CL, RTXL760, RTCLXL745, Titan, and Diamond. Milling yield, averaged across locations and cultivars, was 53-69 (%HR and %TR) during 2016. Mermentau, Jupiter, CL153, CL111, LaKast, and Roy J had the highest milling yields of all commercial entries, averaging 57-70, 57-69, 57-69, 58-67, 55-69, and 55-69, 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 authors wish to thank all Arkansas rice growers for financial support of the Arkansas Rice Performance Trials through the Rice Check-Off funds administered by the Arkansas Rice Research and Promotion Board. We also appreciate the support from the University of Arkansas System Division of Agriculture. We wish to thank the following people for their dedication to making the ARPT possible each year: Chuck Pipkins, Tara Clayton, and Shawn Clark.

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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)	(%)
Caffey	M	1.5	84	38	42.2	23.5	1.69
CL111	L	1.1	80	39	43.0	21.3	1.74
CL151	L	1.9	81	39	42.4	19.8	3.12
CL153	L	1.0	81	39	42.9	20.3	1.57
CL163	L	1.5	85	38	42.3	20.7	1.63
CL172	L	1.0	81	37	42.4	21.6	1.69
CL272	M	1.0	81	38	42.9	22.5	1.89
Diamond	L	1.7	83	41	42.6	21.5	1.23
Jupiter	M	2.5	84	37	41.4	21.1	2.69
LaKast	L	1.2	81	42	42.9	21.8	1.30
Mermentau	L	1.1	82	38	42.7	20.1	2.05
Roy J	L	1.0	87	41	42.1	20.9	1.35
RTCLXL745	L	3.6	78	44	42.9	22.4	2.22
RTXL753	L	1.6	79	44	43.4	21.7	2.68
RTXL760	L	3.3	82	47	42.6	21.0	2.98
Taggart	L	1.5	86	43	42.5	22.7	1.29
Thad	L	1.0	84	38	42.6	20.9	0.53
Titan	M	1.5	79	38	42.4	23.0	1.92
Wells	L	1.1	84	41	42.6	21.7	1.46
Mean		2.2	81	39.3	43.4	21.5	1.84

[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, 2013-2015. Based on weight of 1000 kernels.

averaged across the three-year period of 2014-2016.

Milling yield by year				Grain yield by year			
2014	**2015**	**2016**	**Mean**	**2014**	**2015**	**2016**	**Mean**
------- (% head rice - % total rice) ------				--------------------(bu/acre) -----------------			
57-69	56-68	49-67	54-68	216	179	170	188
63-71	62-70	58-67	61-69	179	144	149	157
65-71	61-70	53-70	60-70	202	166	164	177
--	62-69	57-69	59-69	--	154	169	161
63-70	61-70	54-70	59-70	186	151	150	162
--	58-69	50-69	54-69	--	142	161	152
--	62-70	53-69	58-69	--	162	176	169
61-69	60-69	55-68	59-69	218	186	188	197
59-68	61-68	57-69	59-68	213	176	167	186
62-71	56-68	55-69	58-70	202	162	182	182
66-71	63-69	57-70	62-70	181	161	159	167
62-70	61-70	55-69	59-70	207	169	167	181
61-71	58-69	46-69	55-70	203	187	192	194
57-71	54-69	45-67	52-69	259	212	231	234
--	59-69	52-68	55-68	--	207	205	206
60-70	58-70	47-69	55-70	200	167	179	182
--	58-69	52-70	55-69	--	137	147	142
55-69	56-68	54-69	55-69	235	165	192	197
57-70	57-70	52-69	56-70	192	161	171	175
61-70	59-69	53-69	57-69	207	168	178	182

Table 2. Results of the Arkansas Rice

Cultivar	Grain length[a]	Straw strength[b]	50% heading[c]	Plant height	Test weight
		(rating)	(days)	(in.)	(lb/bu)
Caffey	M	1.0	86	40	38.4
CL111	L	1.0	82	42	39.0
CL151	L	2.8	82	40	38.3
CL153	L	1.0	85	41	39.0
CL163	L	1.3	87	40	38.6
CL172	L	1.0	85	39	38.7
CL272	M	1.0	85	40	39.3
Diamond	L	1.5	85	43	39.1
Jupiter	M	1.8	86	39	37.7
LaKast	L	1.3	82	44	39.3
Mermentau	L	1.0	85	40	38.9
Roy J	L	1.0	90	44	38.7
RT7311 CL	L	2.3	80	46	38.8
RTCLXL745	L	3.5	79	46	38.3
RT Gemini 214 CL	L	2.5	86	48	39.0
RTXL753	L	1.3	80	46	39.6
RTXL760	L	3.3	87	49	38.4
Taggart	L	1.0	88	45	38.9
Thad	L	1.0	88	39	38.9
Titan	M	1.5	80	40	38.9
Wells	L	1.0	85	43	38.8
Mean		1.6	84	42.6	38.8

[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.

[e] CLAY = the Trey Bowers farm in Clay County; NEC = the Newport Extension Center near Newport, Ark.; NEREC = the Northeast Research and Extension Center near Keiser, Ark; PTRS = the Pine Tree Research Station (PTRS) near Colt, Ark.; and RREC = the Rice Research and Extension Center near Stuttgart, Arkansas.

Performance Trials at five locations during 2016.

Milling yield[d]	CLAY[e] 13 April	NEC 23 May	NEREC 25 April	PTRS 11 May	RREC 5 April	Mean
	Grain yield by location and seeding date					
(%HR–%TR)	(bu/acre)					
49–67	196	140	181	162	169	170
58–67	157	111	157	150	170	149
53–70	149	119	177	175	199	164
57–69	180	127	180	165	191	169
54–70	145	131	152	137	184	150
50–69	171	141	170	149	174	161
53–69	198	152	188	178	162	176
55–68	181	163	211	185	202	188
57–69	133	132	207	157	207	167
55–69	194	163	190	173	189	182
57–70	173	125	181	148	169	159
55–69	191	135	187	164	159	167
54–69	183	185	219	207	245	208
46–69	194	163	183	188	235	192
53–69	167	186	224	233	246	211
45–67	252	202	235	209	258	231
52–68	179	182	202	226	238	205
47–69	193	147	197	170	186	179
52–70	156	89	166	128	197	147
54–69	209	155	201	170	223	192
52–69	194	150	189	152	170	171
53–69	181	148	190	173	199	178

Table 3. Rice cultivar reactions[a]

Cultivar	Sheath blight	Blast	Straight-head	Bacterial panicle blight
Caffey	MS	MR	--	MS
Cheniere	S	MS	VS	MS
CL111	VS	MS	S	VS
CL151	S	VS	VS	VS
CL153	S	MS	--	MS
CL163	VS	S	--	MS
CL172	MS	MS	--	MS
CL272	S	MS	--	VS
Cocodrie	S	S	VS	S
Della-2	S	R	--	MS
Diamond	S	S	--	MS
Francis	MS	VS	MR	VS
Jazzman	MS	MR	S	S
Jazzman-2	S	MS	--	VS
JES	S	R	VS	S
Jupiter	S	S	S	MR
LaKast	MS	S	MS	MS
Mermentau	S	S	VS	MS
MM14	--	--	--	S
Rex	S	S	S	S
Roy J	MS	S	S	S
RT7311 CL	MS	--	--	--
RTCL XL729	MS	R	MS	MR
RTCL XL745	S	R	R	MR
RTCL XP756	MS	--	--	--
RT Gemini 214 CL	S	--	--	--
RTXL723	MS	R	S	MR
RTXL753	MS	R	MS	MR
RTXL760	MS	MR	--	MR
Taggart	MS	MS	R	MS
Thad	S	S	S	MS
Titan	S	MS	--	MS
Wells	S	S	S	S

[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. 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.

to diseases (2016).

Narrow brown leaf spot	Stem rot	Kernel smut	False smut	Lodging	Black sheath rot
R	--	--	MS	MR	--
S	S	S	S	MR	MS
S	VS	S	S	MS	S
S	VS	S	S	S	S
S	--	S	S	MR	--
R	--	MS	--	MS	--
S	--	MS	S	MR	--
S	--	MS	--	MR	S
S	VS	S	S	MR	S
MS	--	--	--	--	--
--	S	S	VS	MS	--
S	S	VS	S	MS	S
S	S	MS	S	MS	MS
S	--	S	S	--	--
R	VS	MS	MS	S	MR
MR	VS	MS	MS	S	MR
MS	S	S	S	MS	MS
MS	--	S	S	MS	--
--	--	--	S	--	--
MS	S	S	S	MR	S
R	S	VS	S	MR	MS
--	--	S	--	MS	--
R	S	MS	S	S	S
R	S	S	S	S	S
--	--	--	S	--	S
--	--	MS	--	MS	--
MS	S	MS	S	MS	S
R	--	MS	S	MS	S
R	--	MS	VS	S	--
MS	S	S	S	MS	MS
-	-	S	VS	MR	-
--	--	MS	MS	MS	--
S	VS	S	S	MS	MS

Grain Yield Response of Six New Rice Cultivars to Seeding Rate

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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 six rice cultivars evaluated in 2016 were CL153, CL172, Diamond, LaKast, Roy J, and Titan. Each cultivar was seeded at 20, 40, 60, 80, and 100 lb/acre. In accordance with current recommendations and predominant grower practice, all seed received insecticide and fungicide seed treatments. Trials were seeded at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC) near Stuttgart, Ark.; the Pine Tree Research Station (PTRS) near Colt, Ark.; and the Northeast Research and Extension Center (NEREC) near Keiser, Arkansas. Stand density and grain yield results were consistent with current University of Arkansas System Division of Agriculture's Cooperative Extension Service seeding rate recommendations of 60 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 (36 seed/ft^2; ~80 lb/acre) compared to a loamy soil and optimum seeding date. 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. Grain yield response to seeding rate was generally reduced in 2016 compared to previous research. Reduced grain yield was observed at the lowest (20 lb/acre) seeding rate. As to the influence of seeding rate on milling yield during 2016, percent head rice tended to decrease as seeding rate increased and percent total white rice was not generally influenced.

Introduction

The cultivar × seeding rate studies measure the grain yield performance of new rice (*Oryza sativa* L.) cultivars over a range of seeding rates on representative silt loam

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and clay soils and determine the proper seeding rate to maximize yield on these soils under climatic conditions that exist in Arkansas. Optimal stand density for pure-line cultivars is considered to be 10 to 20 plants/ft^2 (Wilson et al., 2013). Seeding rate is then adjusted as needed to meet field-specific conditions. In general, rice is seeded at 30 seed/ft^2 on silt loam soils and 36 seed/ft^2 on clay soils. Use of an insecticide seed treatment has increased in recent years and is currently used on approximately 68% of the rice acres in Arkansas (Hardke, 2016). 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.

The release of new cultivars, combined with changes in production practices including the use of insecticide and fungicide seed treatments, requires the continued evaluation of seeding rates for new cultivars to ensure recommendations maximize profit potential for rice growers. The objective of this study was to determine the optimal seeding rate for six new rice cultivars in environments and growing conditions common to Arkansas rice production.

Procedures

The three locations for the 2016 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 Calhoun silt loam; and the Northeast Research and Extension Center (NEREC) near Keiser, Ark., on a Sharkey clay. The pure-line cultivars CL153, CL172, Diamond, LaKast, Roy J, and Titan were seeded at RREC, PTRS, and NEREC on 6 May, 11 May, and 25 April, respectively. All seed was treated with CruiserMaxx® Rice seed treatment containing an insecticide and fungicides. 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 25 seed/ft^2 for CL153, 26 seed/ft^2 for CL172, 27 seed/ft^2 for Diamond, 26 seed/ft^2 for LaKast, 27 seed/ft^2 for Roy J, and 22 seed/ft^2 for Titan. Plots were 9 rows (7-in. spacing) wide and 15 ft in length. Cultural practices otherwise followed the University of Arkansas System Division of Agriculture's Cooperative Extension Service 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 a total of 10 row feet. Nitrogen (N) was applied to studies at the 4- to 5-lf growth stage in a single preflood application of 130 lb N/acre as urea on silt loam soils and 160 lb N/acre on clay soils. 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 (a bushel of rice weighs 45 lb).The dried rice was milled to obtain percent head rice (%HR, whole kernels) and percent total white rice (%TR) to provide a milling yield expressed as %HR and %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

At the NEREC on a clay soil, stand density increased as seeding rate increased from 20 to 80 lb/acre and remained constant when seeding rate increased from 80 to 100 lb/acre (Table 1). Stand density within the recommended range of 10 to 20 plants/ft^2 was obtained using a range of 60 to 100 lb seed/acre at this location, but was significantly highest using the seeding rate of 80 lb/acre. This is in agreement with current recommendations to increase seeding rate by 20% when seeding on a clay soil.

At the PTRS, stand density increased incrementally as seeding rate increased from 20 to 100 lb seed/acre. Optimal stand density within the recommended range was obtained at a seeding rate of 60 lb/acre during 2016. Stand density greater than the recommended maximum of 20 plants/ft^2 was noted when using a seeding rate of 80 or 100 lb/acre at this location during 2016. Lodging and disease pressure typically increase when greater than optimal stand densities are reached.

Stand density at the RREC increased as seeding rate increased from 20 to 100 lb seed/acre. During 2016, all seeding rates resulted in stand density within the recommended range, with the exception of lower stand density when seeded at 20 lb/acre. A seeding rate of 80 or 100 lb/acre resulted in optimal stand density at the RREC, which is higher than the current seeding-rate recommendation when planting in the optimal window on a silt loam soil.

Grain yield was not influenced by a cultivar × seeding rate interaction during 2016. The main effect of seeding rate did have a significant influence on grain yield at all locations (Table 2). At the NEREC, the seeding rate of 80 lb/acre resulting in the maximum grain of 191.4 bu/acre. Grain yield increased significantly as seeding rate increased from 20 to 80 lb/acre, but did not significantly increase above 80 lb seed/acre. At the PTRS, no significant difference in grain yield was observed between seeding rates of 40 to 100 lb/acre. Grain yield at the RREC increased numerically as seeding rate increased from 20 to 100 lb/acre, and the highest seeding rate of 100 lb/acre resulted in the highest grain yield (147.1 bu/acre). However at seeding rates of 40 to 100 lb/acre, grain yields ranged from 140.8 to 147.1 bu/acre, respectively. The lowest seeding rate of 20 lb seed/acre resulted in the lowest grain yield at each study location during 2016.

Percent head rice did not vary greatly between seeding rates, but tended to decrease as seeding rate increased in the three studies during 2016 (Table 3). At each location, the lowest seeding rate of 20 lb/acre resulted in the lowest stand density as expected, but in contrast resulted in a higher %HR yield. Percent total white rice was not influenced by seeding rate at the NEREC or RREC studies during 2016. At the PTRS, %TR was statistically different between seeding rates, but varied numerically by <1%. Milling yield results from 2016 were somewhat dissimilar to results from the same study conducted in 2015 (Hardke et al., 2016). During 2015, samples collected from the NEREC and PTRS study locations found that 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. Samples were not taken from the RREC study during 2015.

A comparison of grain yields by converting to percent of optimal yield at each location is provided in Fig. 1. At NEREC, all seeding rates resulted in greater than 92% optimal grain yields; at PTRS, all seeding rates resulted in greater than 92% optimal grain yields; and at RREC all seeding rates resulted in greater than 89% optimal grain yields. Seeding rates of 40 lb/acre or greater resulted in optimal grain yields of 95% or more at all locations. These results are in contrast to the same study in 2015 (Hardke et al., 2016) which showed a more significant yield penalty for lower seeding rates.

Significance of Findings

The cultivar × seeding rate studies in 2016 agree with previous research that an optimum seeding rate for new rice cultivars is approximately 30 seed/ft^2. This corresponds to a seeding rate of 65 to 80 lb seed/acre depending on seed size of individual cultivars. Seeding rates lower than the current recommendation 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.

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Table 1. Influence of seeding rate on stand density at three locations during 2016.

	Stand density[†]		
Seeding rate	**NEREC[‡]**	**PTRS**	**RREC**
(lb seed/acre)	-------------------------(bu/acre)------------------------		
20	5.1 dc[§]	6.4 e	6.5 c
40	8.8 c	12.2 d	11.0 b
60	10.6 b	16.2 c	12.2 b
80	13.3 a	20.5 b	14.5 a
100	13.8 a	23.5 a	15.4 a
$LSD_{0.05}$[¶]	1.4	1.2	1.8

[†] Averaged across CL153, CL172, Diamond, LaKast, Roy J, and Titan 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 ($P > 0.05$).
[¶] LSD = least significant difference.

Table 2. Influence of seeding rate on rice grain yield at three locations during 2016.

	Stand density[†]		
Seeding rate	**NEREC[‡]**	**PTRS**	**RREC**
(lb seed/acre)	-------------------------(bu/acre)------------------------		
20	177.2 dc[§]	157.2 b	131.9 c
40	185.3 c	166.5 a	140.8 b
60	187.1 bc	168.4 a	142.0 b
80	191.4 a	165.4 a	144.0 ab
100	189.9 ab	170.6 a	147.1 a
$LSD_{0.05}$[¶]	3.9	6.0	4.3

[†] Averaged across CL153, CL172, Diamond, LaKast, Roy J, and Titan 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 ($P > 0.05$).
[¶] LSD = least significant difference.

Table 3. Influence of seeding rate on rice milling yield at three locations during 2016.

	Milling yield†		
Seeding rate	NEREC‡	PTRS	RREC
(lb seed/acre)	----------	(%HR-%TR§)	----------
20	61.1 abd¶-69.8	51.7 a-68.9 ab	57.8 a-70.2
40	61.3 a-70.3	51.5 a-69.3 a	57.3 ab-70.4
60	60.4 bc-69.9	50.9 ab-68.9 ab	55.9 c-69.9
80	60.1 c-69.8	49.7 b-68.7 b	56.2 c-70.0
100	60.2 c-69.8	49.5 b-68.6 b	56.5 bc-70.3
$LSD_{0.05}$#	0.8-NS††	1.6-0.4	1.1-NS

† Averaged across CL153, CL172, Diamond, LaKast, Roy J, and Titan 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.
§ %HR-%TR = %head rice and %total white rice.
¶ Means within a column followed by the same letter are not significantly different ($P > 0.05$).
# LSD = least significant difference.
†† NS = not significant.

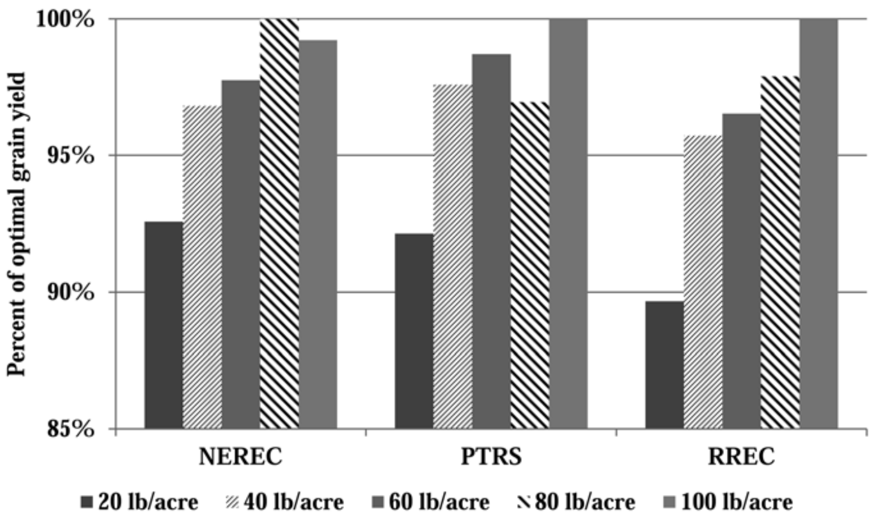

Fig. 1. Influence of seeding rate on rice grain yield at the Northeast Research and Extension Center (NEREC), Pine Tree Research Station (PTRS), and Rice Research and Extension Center (RREC) during 2016.

Methane Emissions from Rice Production Across a Soil Organic Matter Concentration Gradient

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Abstract

Quantifying greenhouse gas (GHG) emissions in agricultural settings has become of upmost importance in determining the magnitude of impact on global climate change. Understanding the preexisting conditions needed to produce GHGs, such as methane (CH_4), is essential in attenuating the release of excessive GHGs. The objective of this study was to evaluate the effects of soil organic matter (SOM) concentration on CH_4 emissions from rice (*Oryza sativa* L.) grown in varying silt loam soils. Eight soils were collected from various locations around east-central Arkansas to represent a SOM concentration gradient for this field study. The soils were placed in plastic tubs that were buried in a single bay with the pure-line rice cultivar LaKast transplanted into each tub and grown to harvest maturity under a full-season flood. The SOM concentration ranged from 1.5% to 4.2%, while the corresponding CH_4 emissions and grain yields ranged from 135 to 1424 kg CH_4-C/ha/season and 9374 to 17,489 kg/ha (186 to 347 bu/acre), respectively. Rice grown in soil from a managed grassland (MG), which had the largest SOM, produced the second numerically largest CH_4 emissions (1189 kg CH_4-C/ha/season) and the numerically largest grain yield of 347 bu/acre (17,489 kg/ha). The numerically lowest CH_4 emissions of 135 kg CH_4-C/ha/season came from the cultivated agriculture (CA-25), which had a yield of 186 bu/acre (9374 kg/ha). Methane emissions increased linearly with increasing SOM concentration ($R^2 = 0.86$). Greater understanding of the influence of SOM concentration on CH_4 emissions from rice fields is essential in assessing GHG impacts from rice production.

Introduction

Global climate change is the greatest challenge humans will collectively face in the next 100 years. As rainfall patterns change, global temperatures increase, and

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human populations rise, increasing food production via soil health and water resource management will become paramount for continued survival. Natural resource management tools are needed in agricultural production to not only increase yield, but reduce climate-change drivers, such as greenhouse gas (GHG) emissions. The challenges of population increase require that a clear understanding of current conditions and practices exists so that innovative techniques can be developed and implemented to off-set potential negative agronomic and ecological/environmental effects of climate change.

Methane (CH_4) is a potent GHG and is produced in flooded-soil conditions due to the absence of oxygen in the soil (i.e., anoxic or anaerobic conditions) as a byproduct of chemical carbon (C) reduction. During C reduction, C in soil organic matter (SOM) is converted to CH_4 by a class of microorganisms known as methanogens. Methanogens use fermentation products, such as acetic acid, that are produced by other soil microbes as a food and energy source and produce CH_4 as a waste product. The main agricultural sources of CH_4 in the U.S. are enteric fermentation and manure management, with over 95% of total agriculturally related CH_4 emissions as of 2012 (IPCC, 2014). However, rice cultivation and residue burning make up 3.7% of the total agricultural CH_4 releases (IPCC, 2014).

Since CH_4 can only be produced if there is a source of reducible C in the soil, it stands to reason that soils with greater initial SOM concentrations would produce greater amounts of CH_4. However, this relationship has not been demonstrated. Therefore, the objective of this field study was to evaluate the effect of SOM concentration on season-long CH_4 emissions from a pureline cultivar grown under a full-season flood. It was hypothesized that CH_4 emissions would be related to initial SOM concentration, and specifically increase non-linearly as SOM concentration increased.

Procedures

Field research was performed in 2016 at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC) near Stuttgart, Ark., and closely followed procedures outlined in Rogers et al. (2014). The RREC is located in a region known as the Grand Prairie, which is part of the Major Land Resource Area 131D, Southern Mississippi River Terraces, within Arkansas County (USDA, 2006).

Treatments in this field study consisted of eight soils collected from various locations around east-central Arkansas that established a SOM concentration gradient (Table 1). Two soils were collected from the University of Arkansas System Division of Agriculture's Pine Tree Research Station in St. Francis County near Colt, Ark., one from a Calhoun silt loam (fine-silty, mixed, active, thermic Typic Glossaqualfs) under cultivated agricultural land-use (CA-PT) and one from a Henry silt loam (Coarse-silty, mixed, active, thermic Typic Fragiaqualfs) under Conservation Reserve Program (CRP) managed grassland land-use that had not been under cultivated agriculture for at least 15 years. Four soils were collected from a private farmstead (i.e., the Seidenstricker Farm) north of Stuttgart, Ark., where one was a DeWitt silt loam from a native tallgrass prairie (NP) and the other three soils were from cultivated agricultural land-use under varying years of continuous annual cultivation [i.e., 30 years from a DeWitt silt loam

(CA-30) and 41 (CA-41) and 59 (CA-59) years from a Stuttgart silt loam (fine, smectitic, Albaquultic Hapludalfs)]. Two DeWitt silt loam (fine, smectitic, thermic Typic Albaqulfs; USDA, 2015) soils under contrasting landuses were collected from the RREC. One soil had been under cultivated agriculture for at least 25 years (CA-25), while the other soil was from a managed grassland (MG; i.e., lawn turf) . Additional characteristics of the eight soils and sites they were collected from are summarized in Table 1.

At each site, soil was manually excavated to a depth of approximately 50 cm (20 in.). First, the upper approximately 20 cm (8 in.) of soil was removed and temporarily set aside, while the remaining sub-soil, approximately 20- to 45-cm (8- to 18- in.) depth interval, was manually excavated and placed into a 33-cm wide × 60.7-cm long × 42.6-cm deep (13-in. wide × 24-in. long × 17-in. deep), high-density, commercially available plastic bin. Once the sub-soil was in place in the plastic bin, approximately 20 cm (8 in.) in depth, the upper 20 cm (8 in.) of topsoil was placed in the bin on top of the sub-soil to recreate the original soil profile horizon sequence as best as possible. Each of the eight soils collected from the various sites were replicated three times for a total of 24 bins. All soil-containing bins were transported to the RREC and on 7 May 2016 were randomly placed within two, 5-m wide × 3-m long (16.4-ft wide × 9.8-ft long) areas adjacent to one another that were excavated manually to a depth of approximately 30 cm (12 in.). Once all 24 bins had been placed in the excavated areas, soil was back-filled around the bins to bury them such that the soil level inside the bins was at the level of the surrounding natural soil. After back-filling soil around the bins, the top ~ 10 cm (4 in.) of the soil surface in each bin was manually disturbed to break up large clods to create a semi-smooth, uniformly appearing, level seed bed into which rice plants would be transported. On 20 May 2016, approximately 10-cm-tall seedling plants from a nearby field plot, that had been drill-seeded with the pure-line rice cultivar LaKast on 23 April 2016, were manually transplanted 2- to 4-cm (0.75- to 1.5-in.) deep into two rows 18-cm (7 in.) apart in each bin to match the planting density in the surrounding drill-seeded plot, which was approximately 320 plants/m^2 (30 plants/ft^2) On 8 June 2016, the transplanted rice in the bins was manually broadcast-fertilized pre-flood at an optimum recommended rate of 117 kg N/ha (104 lb/acre) with urea (46% N) [i.e., 5.77 g (0.01277 lb) urea per bin]. A levee had been previously established around the buried bins and the permanent flood was established immediately after N fertilization (i.e., 9 June 2016) and maintained at a depth of approximately 10 cm (4 in.) until maturity. On 27 June 2016, 18 days after flood establishment, the split N application of 117 kg N/ha was manually broadcast-applied [i.e., 5.77 g (0.01277 lb) urea per bin] to the floodwater mid-season at beginning of internode elongation. The pre-flood nitrogen amount was used to offset the transplant shock of the rice plants. On 23 August 2016, the flood was released from the bay containing the 24 transplanted bins.

Soil Sample Collection, Processing, and Analyses

Prior to flood establishment, 28 May 2016, 2 soil cores, 2.4 cm in diameter, were collected with a manual push probe from the top 10 cm (4 in.) in each of the 24 bins for chemical analyses. All soil samples were dried at 70 °C for 72 h, crushed, and sieved through a 2-mm mesh screen for soil property determinations. Soil organic matter and total carbon (TC) concentration was determined by weight-loss-on-ignition after 2 h at 360 °C.

One base collar for sampling, 30-cm in diameter × 30-cm tall, was then set into place in the center of each bin encompassing the majority of both manually transplanted rice rows. Base collars were constructed out of 0.6-cm thick Schedule 40 polyvinyl chloride (PVC) material and beveled to a 45° angle to the outside at the base to facilitate insertion. Base collars were inserted ~10 cm (4 in.) into the soil so that four 1.25-cm diameter holes 12 cm from the bottom of the base collar were ~1 cm above the soil to facilitate flood-water movement into and out of the base collar.

Vented, non-steady-state, non-flow-through chambers (Livingston and Hutchinson, 1995) made out of 30-cm Schedule 40 PVC were used for the acquisition of gas samples for the purpose of determining CH_4 fluxes. To prevent convection currents inside of the chambers that would dilute the ambient, headspace air during sampling, the holes in the base collars were plugged with gray butyl-rubber septa (Voigt Global, part# 73828A-RB, Lawrence, Kan.) during sampling after flood release.

Chamber extensions, 40 and 60 cm in length depending on the height of the rice plants at the time of sampling, were used to accommodate rice growth during the season. Reflective aluminum tape (CS Hyde, Mylar metallized tape, Lake Villa, Ill.) was used to cover chamber extensions to reduce temperature variations inside the chamber during use. Tire inner tube cross sections were cut to approximately 10-cm wide and taped to the bottom of all the extensions to function as a seal between the base collar and the chamber extensions during gas sampling.

Chamber caps were constructed with 10-cm tall sections of 30-cm diameter PVC, with a 5-mm thick sheet of PVC glued to the top and covered with reflective aluminum tape. Tire inner tube cross sections, approximately 10-cm wide, were also taped to the bottom of the caps to serve as a seal between the chamber base collar early in the growing season or upper-most extension later in the season. A 15-cm long piece of 4.5-mm inside diameter (id) copper refrigerator tubing was installed into the side of each cap to maintain atmospheric pressure during gas sampling. On the top of the gas-chamber caps, 12.5-mm (0.5-in.) diameter holes were drilled and plugged with gray butyl-rubber septa (Voigt Global, part# 73828A-RB, Lawrence, Kan.) for syringe and thermometer insertion. To ensure adequate air mixing in the enclosed gas chamber, a 2.5-cm tall × 2.5-cm wide electric, 9V-battery-operated, magnetic levitation fan (Sunon Inc., MagLev, Brea, Calif.) was installed and operated for the duration of gas sampling.

The collection of gas samples from the enclosed chambers was achieved by using a 20-mL B-D syringe with a removable 0.5-mm diameter × 25-mm long needle (Beckton Dickson and Co., Franklin Lakes, N.J.) that was inserted through the gray butyl-rubber septa installed in the chamber cap. After drawing a gas sample from the chamber, the collected sample was immediately injected into a pre-evacuated, 10-mL, crimp-top glass vial (Agilent Technologies, part# 5182-0838, Santa Clara, Calif.). Gas sampling occurred weekly between flooding and flood release starting 5 d after flooding. On each sample date, gas samples were collected at 20-min intervals for 1 h, after the chamber was capped and sealed (i.e., the 0-, 20-, 40-, and 60-min marks). At the end of the growing season, prior to harvest, gas-sampling occurred 1, 5, and 6 d after flood release. Similar to prior studies (Rogers et al., 2013, 2014), all gas sampling started in the morning between 0800 to 0830 hours to minimize temperature fluctuations in the chambers and to maintain continuity with previous research studies.

During each chamber sampling event, 10-cm (4-in.) soil temperature, relative humidity, ambient air temperature, barometric pressure, and the air temperature inside the chamber were recorded at every sampling interval (i.e., the 0-, 20-, 40-, and 60-min marks). At the end of each gas sampling event, the chamber height to the current water level was recorded so that the interior chamber volume could be calculated. Samples of CH_4 gas standards (i.e., 2, 5, 10, 20, and 50 mg/L) were collected in the field using a 20-mL B-D syringe with a detachable 0.5-mm diameter × 25-mm long needle that was immediately injected into a pre-evacuated, 10-mL, crimp-top glass vial. Immediately prior to field sample analyses, CH_4 gas samples from the same five gas standards were also collected in the laboratory.

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 × 30-m HP-Plot-Q capillary column (Agilent Technologies), gas samples were analyzed for CH_4 concentrations within 48 h of collection. In procedures outlined by Rogers et al. (2014), CH_4 fluxes were calculated according to changes in concentrations in the chamber headspace over the 60-min sampling interval. Measured concentrations (mL/L; y axis) were regressed against time (min; x axis) of sample extraction (i.e., 0, 20, 40, and 60 min) to determine the change in concentration over time. Seasonal emissions were calculated on a chamber-by-chamber basis by linear interpolation between sample dates.

Plant Sampling and Processing

Eight days after the last gas sampling, all aboveground biomass was collected from the interior of each base collar. Plants were cut approximately 2 cm (0.75 in.) above the soil surface and placed in a drying chamber at 55 °C for 3 weeks then weighed to determine aboveground dry matter. To obtain grain yields from the bins, the panicles were removed from the aboveground dry matter samples from the bins, manually threshed to separate the grain from the panicles, and weighed. Yield was calculated based on grain mass per collar area. Rice grain yields were corrected to 12% grain moisture for reporting purposes. Total season-long CH_4 emissions were divided by total rice grain yield on a bin-by-bin basis to express emissions on a per-unit-grain-yield basis.

Statistical Analyses

Based on a completely random design, a one-factor analysis of variance was conducted to determine the effect of SOM concentration on total growing-season CH_4 emissions. Regression analyses were also conducted to evaluate the relationship between total growing-season CH_4 emissions and SOM concentration. When appropriate, means were separated by least significant difference (LSD) at the 0.05 level.

Results and Discussion

Initial SOM concentrations ranged from 1.5% to 4.2% (Table 2). Managed grassland contained the greatest SOM concentration (4.2%), which differed ($P < 0.05$) from that in all other treatments. Mean season-long CH_4 emissions ranged from 134 kg CH_4-C/h/season from the cultivated agriculture (CA-25) to 1424 kg CH_4-C/ha/season from the native tallgrass prairie (NP), while mean rice grain yields ranged from 9374 kg/ha (186 bu/acre) from the CA-25 to 17489 kg/ha (347 bu/acre) from the managed grassland (MG). The three treatments with the numerically largest mean CH_4 efficiency (i.e., lowest CH_4 emissions per unit grain yield produced) were CA-30, CA-41, and CA-25 at 12.3, 12.4, and 14.4 kg CH_4-C/Mg grain, respectively. The treatments with the numerically lowest mean CH_4 efficiency (i.e., greatest CH_4 emissions per unit grain yield produced) were CA-PT, MG, and NP at 42.9, 68.0, and 87.2 kg CH_4-C/Mg grain, respectively. Using the CH_4 emissions and SOM and TC concentration data from the eight treatments, there was a strong, positive linear relationship between season-long CH_4 emissions, and SOM ($R^2 = 0.86$) and TC ($R^2 = 0.85$) concentration (Fig. 1). The linear relationship demonstrates that CH_4 emissions increase as initial SOM or TC concentration increases.

Significance of Findings

The results of this field study clearly demonstrate that season-long CH_4 emissions are strongly related to initial amounts of SOM and/or TC in the soil prior to planting rice. Methanogens appear to have more than an equally finite capacity under anaerobic conditions to reduce C and produce CH_4 as long as a readily reducible source of C substrate (i.e., SOM) is available. Consequently, initial SOM concentration may need to be considered an important CH_4-production-related factor in silt loam soils. Continued investigation is needed to understand the effects of initial soil property differences in common silt loam soils used for rice production in the Lower Mississippi River Valley, particularly the Delta region of eastern Arkansas to help mitigate CH_4 emissions, while maintaining rice yields for Arkansas producers.

Acknowledgments

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Table 1. Summary of landuse, treatment abbreviation, Major Land Resource Area (MLRA) classification, soil series, soil taxonomic description, and unique feature of soils used in 2016 to measure methane emissions.

Landuse†	MLRA	Soil series	Taxonomic description	Unique feature
		(silt loam)		
CRP	134	Henry	Typic Fragiaqualfs	> 15 y in CRP
CA-PT	134	Calhoun	Typic Glossaqualfs	rice/soybean rotation
CA-25	131D	DeWitt	Typic Albaqualfs	> 25 y rice/soybean rotation
MG	131D	DeWitt	Typic Albaqualfs	lawn of station headquarters
CA-59	131D	Stuttgart	Albaquultic Hapludalfs	59 y rice/soybean rotation
CA-41	131D	Stuttgart	Albaquultic Hapludalfs	41 y rice/soybean rotation
CA-30	131D	Dewitt	Typic Albaqualfs	30 y rice/soybean rotation
NP	131D	Dewitt	Typic Albaqualfs	native tallgrass prairie

† Conservation resource program (CRP), cultivated agriculture (CA-PT), cultivated agriculture (CA-25), managed grassland (MG), cultivated agriculture (CA-59), cultivated agriculture (CA-41), cultivated agriculture (CA-30), and native prairie (NP).

Table 2. Summary of land use treatments, total carbon (TC) and soil organic matter (SOM) concentrations, season-long methane (CH_4) emissions, rice yield, and CH_4 emissions per unit grain yield for measurements collected during the 2016 rice growing season at the Rice research and Extension Center near Stuttgart, Ark.

Landuse†	TC	SOM	Methane emission	Rice yield	Rice yield	Emissions: yield ratio
	------- (%) --------		(kg CH_4-C/ha /season)	(kg/ha)	(bu/acre)	(kg CH_4-C/ mg grain)
CRP	1.03	2.4 c‡	663	15447	232	42.9
CA-PT	0.87	1.9 de	358	12099	181	29.6
CA-25	0.48	1.5 e	135	9374	141	14.4
MG	1.86	4.2 a	1189	17489	262	68.0
CA-59	0.74	1.7 de	378	9698	145	38.9
CA-41	0.89	1.7 de	159	12786	192	12.4
CA-30	0.95	2.1 cd	179	14578	219	12.3
NP	2.04	3.6 b	1424	16319	245	87.2

† Conservation resource program (CRP), cultivated agriculture (CA-PT), cultivated agriculture (CA-25), managed grassland (MG), cultivated agriculture (CA-59), cultivated agriculture (CA-41), cultivated agriculture (CA-30), and native prairie (NP).

‡ Means followed by the same letter do not differ ($P > 0.05$).

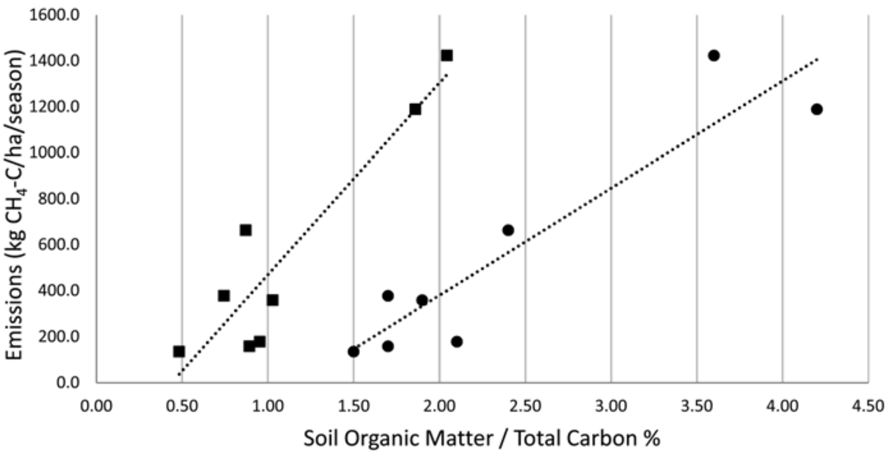

Fig. 1. Season-long methane (CH_4-C) emissions from the 2016 growing season conducted at the Rice Research and Extension Center near Stuttgart, Ark. The linear equation associated with soil organic matter (solid circles) is *y* = 466.29x − 552.76 (R^2 = 0.86), while the linear equation associated with total carbon (solid squares) is *y* = 835.07x − 365.85 (R^2 = 0.85).

Utilization of On-Farm Testing to Evaluate Rice Cultivars, 2016

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Abstract

On-farm testing provides researchers the opportunity to evaluate cultivars in a more unpredictable environment than that of the research farm or traditional test plot. The Producer Rice Evaluation Program (PREP) utilizes commercial rice fields throughout the state to evaluate experimental lines and various commercial cultivars for disease, lodging, grain yield potential, and milling yield 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 Conway, Crittenden, Greene, Lawrence, Poinsett, Mississippi, White, and Woodruff counties during the 2016 growing season. Twenty cultivars were selected for evaluation in the on-farm tests. The average grain yield across all locations was 198 bu/acre and the mean milling yield (% head rice and %total white rice; %HR and %TR) was 52-70. The cultivars with the highest grain yields averaged across locations were RT XL753, RT Gemini 214 CL, RT 7311 CL, RT XL760, RT CLXL745, Titan, and Jupiter. Mermentau, CL153, CL163, and CL172 had the highest milling yields averaged across locations.

Introduction

One goal of the University of Arkansas System Division of Agriculture is to offer a complete production package to producers when southern U.S. rice cultivars are released, including grain and milling yield potential, disease reactions, fertilizer recommendations, and Degree-Day 50 (DD50) Program thresholds. Factors that can influence grain yield potential include: seeding date, soil fertility, water quality and management, disease pressure, weather events, and cultural management practices.

Rice disease can be a major factor in the profitability of any rice field in Arkansas. Host-plant resistance, optimum farming practices, and 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 System Division of Agriculture under controlled experiment station conditions. A large set of data on grain yield, grain quality, plant growth habit, and major disease resistance is collected during this process. Unfortunately, the dataset under these conditions is not complete for many of the environments where rice is grown in Arkansas because potential problems may not be evident in nurseries grown on experiment stations. With 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 those conditions not commonly observed on experiment stations.

Procedures

Field studies were located in Conway, Crittenden, Greene, Lawrence, Mississippi, Poinsett, White and Woodruff counties during the 2016 growing season. Twenty cultivars were selected for evaluation in the on-farm tests. Non-Clearfield entries evaluated during 2016 included Diamond, Jupiter, LaKast, Mermentau, RT XL753, RT XL760, Roy J, Thad, and Titan. Clearfield lines included CL111, CL151, CL153, CL163, CL172, CL272, CLX1024, CLX1111, RT 7311 CL, RT CLXL745, and RT Gemini 214 CL.

Plots were 9 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 (loam soil) or 36 seed/ft^2 (clay soil) while hybrids were seeded at a rate of 10.3 seed/ft^2 (loam soil) or 12.4 seed/ft^2 (clay soil). Trials were seeded on 8 April (Lawrence and Woodruff), 13 April (Greene and Poinsett), 15 April (Crittenden and Mississippi), and 26 April (Conway and White). 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 and %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 2016 growing season; a summary of the results by county and corresponding date of seeding is presented in Table 1. Across counties, the grain yield averaged 198 bu/acre. RT XL753 and RT Gemini 214 CL were the highest-yielding cultivars followed by RT XL760, RT 7311 CL, and Titan. In the Conway Co. trial (Table 2), grain yield averaged 208 bu/acre. The highest-yielding entries were RT Gemini 214 CL, RT XL760, Roy J and CLX1111. The highest-yielding entries for %HR were CL153, CL163, CLX1024, and Mermentau. In the Crittenden Co. trial (Table 3), grain yield for the location averaged 216 bu/acre. The highest-yielding cultivars were RT XL753, RT Gemini 214 CL, RT XL760 and RT 7311 CL. Percent head rice averaged 62% at Crittenden Co. during 2016 with CL111, CL151, CLX1024, and Mermentau obtaining the location maximum of 66 %HR. RT Gemini 214 CL, RT XL760, RT 7311, and Jupiter were the highest-yielding cultivars in the Greene Co. trial (Table 4). Percent head rice of 55% was measured for Mermentau in the Greene Co. trial, followed by CL172 and Jupiter at 54 %HR. The Lawrence Co. trial (Table 5) was the highest average-yielding field at 223 bu/acre, and cultivars with the highest grain yield included RT XL753, Titan, RT 7311 CL, RT Gemini 214 CL, and RT XL760. Highest %HR was noted for CL163 and CL172. In the Mississippi Co. trial (Table 6), RT Gemini 214 CL, RT XL753, RT 7311 CL, and RT XL760 were the highest-yielding cultivars and the average yield for the location was 195 bu/acre. Cultivars with the highest %HR included Mermentau, Jupiter, CL111, CL153, and LaKast. RT XL753, RT 7311 CL, RT Gemini 214 CL, and Titan were the highest-yielding cultivars in Poinsett Co. with a location average of 210 bu/acre (Table 7). Mermentau and CL163 had the highest %HR at this location. White Co. and Woodruff Co. trials each averaged 163 bu/acre (Tables 8 and 9, respectively). The highest-yielding cultivars in White Co. were RT XL753, RT 7311 CL, RT Gemini 214 CL, and RT CLXL745; and in Woodruff Co. were RT Gemini 214 CL, RT CLXL745, CLX1111, and XL753. Cultivars at White Co. with the highest %HR were CL153, CL172, CLX1024, and Mermentau. At the Woodruff Co. location, CL163 and Mermentau had the highest %HR.

Monitoring cultivar response to disease presence and the severity of reactions is a significant part of this program. The observations obtained from these plots are often the basis for disease ratings developed for use by growers (Table 10). 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 2016 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

Cultivar	Grain length[a]	Lodging	Moisture	Test weight	Milling yield[b]
		--------------(%)------------		(lb/bu)	(%HR-%TR)
CL111	L	0.6	15.6	41.4	55-71
CL151	L	22.5	17.2	40.3	55-70
CL153	L	1.3	16.0	41.1	57-71
CL163	L	18.4	16.1	41.1	57-70
CL172	L	2.9	16.9	40.5	57-70
CLX1024	L	4.1	15.7	41.2	55-70
Diamond	L	1.6	17.4	40.7	52-70
LaKast	L	4.7	16.1	41.2	51-70
Mermentau	L	0.0	16.5	40.9	60-71
Roy J	L	0.0	16.7	40.9	53-71
RT 7311 CL	L	3.8	16.2	40.7	48-70
RT CLXL745	L	23.6	16.9	40.4	49-70
RT Gemini 214 CL	L	11.6	15.8	40.8	51-69
RT XL753	L	9.4	16.3	40.9	46-70
RT XL760	L	23.6	16.3	40.7	52-69
Thad	L	0.0	15.6	41.2	55-70
CL272	M	0.0	17.4	40.3	48-68
CLX1111	M	9.7	17.2	40.5	44-68
Jupiter	M	11.3	18.4	40.2	55-68
Titan	M	9.1	17.2	40.6	47-68
Mean	--	7.9	16.6	40.8	52-70
$LSD_{0.05}$[c]	--	6.3	1.1	0.5	2.1-0.5

[a] Grain length: L = long-grain; M = medium-grain.
[b] %HR-%TR = % head rice and % total rice.
[c] LSD = least significant difference.

Program at eight locations during 2016.

Grain yield by location and planting date								
Conway 4/26	Crittenden 4/15	Greene 4/13	Lawrence 4/8	Mississippi 4/15	Poinsett 4/13	White 4/26	Woodruff 4/8	Mean
(bu/acre)								
162	187	188	209	181	162	118	157	171
176	224	194	221	181	193	158	167	189
203	214	201	213	177	199	148	156	189
172	145	185	185	153	177	109	137	158
186	209	186	211	188	195	150	160	186
144	181	195	182	177	179	109	131	162
212	235	201	229	197	220	188	167	206
173	209	199	220	169	208	137	169	185
176	199	199	203	173	183	146	134	177
247	227	200	211	201	201	172	157	202
225	240	230	245	230	249	211	161	224
192	226	224	218	213	215	192	186	208
273	247	248	238	252	247	206	187	237
242	260	224	279	244	250	235	179	239
260	240	234	238	220	233	190	178	224
204	192	210	218	182	188	117	130	180
214	215	216	229	176	211	152	173	198
247	226	211	226	184	220	177	185	209
244	206	226	232	196	236	176	170	211
209	233	214	254	204	240	168	172	212
208	216	209	223	195	210	163	163	198
26.6	23.0	31.8	17.5	27.2	13.5	18.3	18.1	8.6

Table 2. Results of Conway Co. Producer Rice Evaluation Program Trial during 2016.

Cultivar	Grain length[a]	Lodging	Moisture	Test weight	Grain yield	Milling yield[b]
		----------- (%) ----------		(lb/bu)	(bu/acre)	(%HR-%TR)
CL111	L	0.0	19.2	37.3	162	54-69
CL151	L	12.5	23.8	36.0	176	56-71
CL153	L	0.0	22.0	36.4	203	59-71
CL163	L	30.0	24.8	35.4	172	59-71
CL172	L	0.0	23.6	35.5	186	56-70
CLX1024	L	0.0	22.0	36.4	144	59-70
Diamond	L	0.0	22.4	36.4	212	49-69
LaKast	L	0.0	21.7	36.6	173	48-69
Mermentau	L	0.0	23.5	36.0	176	62-71
Roy J	L	0.0	18.7	37.6	247	52-70
RT 7311 CL	L	0.0	19.5	37.2	225	47-69
RT CLXL745	L	0.0	21.5	36.6	192	49-70
RT Gemini 214 CL	L	7.5	17.8	37.7	273	50-69
RT XL753	L	0.0	22.9	36.1	242	49-70
RT XL760	L	10.0	20.5	36.7	260	53-70
Thad	L	0.0	20.3	37.0	204	53-70
CL272	M	0.0	22.2	36.3	214	52-69
CLX1111	M	30.0	20.8	36.8	247	47-70
Jupiter	M	30.0	22.4	36.2	244	58-68
Titan	M	15.0	24.2	35.7	209	51-68
Mean	--	6.8	21.7	36.5	208	53-70
$LSD_{0.05}$[c]	--	19.9	NS[d]	NS	26.6	5.5-1.6

[a] Grain length: L = long-grain; M = medium-grain.
[b] %HR-%TR = % head rice - % total white rice.
[c] LSD = Least significant difference.
[d] NS = not significant.

Table 3. Results of Crittenden Co. Producer Rice Evaluation Program Trial during 2016.

Cultivar	Grain length[a]	Lodging	Moisture	Test weight	Grain yield	Milling yield[b]
		----------- (%) ----------		(lb/bu)	(bu/acre)	(%HR-%TR)
CL111	L	0.0	16.0	49.0	187	66-73
CL151	L	5.0	17.4	46.6	224	66-73
CL153	L	0.0	17.0	47.5	214	65-73
CL163	L	72.5	14.5	49.2	145	61-71
CL172	L	0.0	17.5	47.1	209	65-72
CLX1024	L	0.0	16.1	47.8	181	66-73
Diamond	L	0.0	22.7	46.9	235	58-71
LaKast	L	0.0	16.3	48.8	209	61-72
Mermentau	L	0.0	17.3	48.2	199	66-72
Roy J	L	0.0	23.3	46.6	227	60-72
RT 7311 CL	L	0.0	17.1	46.9	240	59-72
RT CLXL745	L	12.5	18.2	46.7	226	59-72
RT Gemini 214 CL	L	0.0	16.9	47.2	247	60-71
RT XL753	L	0.0	18.3	47.4	260	59-72
RT XL760	L	25.0	17.6	46.3	240	60-71
Thad	L	0.0	17.0	48.4	192	62-70
CL272	M	0.0	18.9	46.6	215	63-70
CLX1111	M	0.0	19.5	47.5	226	59-70
Jupiter	M	0.0	27.5	45.1	206	62-67
Titan	M	0.0	18.3	47.2	233	64-71
Mean	--	5.8	18.4	47.3	216	62-71
$LSD_{0.05}$[c]	--	8.9	2.8	1.7	23.0	2.1-1.1

[a] Grain length: L = long-grain; M = medium-grain.
[b] %HR-%TR = % head rice - % total white rice.
[c] LSD = Least significant difference.

Table 4. Results of Greene Co. Producer Rice Evaluation Program Trial during 2016.

Cultivar	Grain length[a]	Lodging	Moisture	Test weight	Grain yield	Milling yield[b]
		----------- (%) ----------		(lb/bu)	(bu/acre)	(%HR-%TR)
CL111	L	0.0	15.4	39.6	188	49-69
CL151	L	0.0	16.7	38.9	194	51-68
CL153	L	0.0	14.9	39.9	201	52-69
CL163	L	0.0	15.3	39.7	185	52-68
CL172	L	0.0	18.4	37.7	186	54-69
CLX1024	L	0.0	16.1	39.3	195	47-68
Diamond	L	0.0	15.6	39.6	201	47-68
LaKast	L	0.0	15.2	39.8	199	44-67
Mermentau	L	0.0	16.3	39.1	199	55-69
Roy J	L	0.0	15.9	39.2	200	50-69
RT 7311 CL	L	0.0	16.6	38.9	230	41-68
RT CLXL745	L	0.0	16.4	38.9	224	46-68
RT Gemini 214 CL	L	0.0	15.6	39.3	248	50-68
RT XL753	L	0.0	15.0	39.8	224	39-68
RT XL760	L	15.0	16.3	39.0	234	47-67
Thad	L	0.0	16.9	38.8	210	52-68
CL272	M	0.0	17.1	38.7	216	49-67
CLX1111	M	2.5	18.2	37.9	211	44-66
Jupiter	M	0.0	15.3	39.8	226	54-66
Titan	M	0.0	16.1	39.2	214	45-67
Mean	--	0.9	16.1	39.1	209	48-68
$LSD_{0.05}$[c]	--	6.2	NS[d]	NS	31.8	6.8-1.6

[a] Grain length: L = long-grain; M = medium-grain.
[b] %HR-%TR = % head rice - % total white rice.
[c] LSD = Least significant difference.
[d] NS = not significant.

Table 5. Results of Lawrence Co. Producer Rice Evaluation Program Trial during 2016.

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	41.2	209	58-73
CL151	L	0.0	13.3	40.9	221	57-71
CL153	L	0.0	12.6	41.3	213	58-72
CL163	L	0.0	13.6	40.7	185	59-72
CL172	L	0.0	14.2	40.3	211	59-72
CLX1024	L	0.0	13.3	40.8	182	58-72
Diamond	L	0.0	15.2	39.7	229	57-71
LaKast	L	0.0	13.9	40.5	220	60-73
Mermentau	L	0.0	14.1	40.4	203	61-72
Roy J	L	0.0	14.6	39.9	211	58-73
RT 7311 CL	L	0.0	15.3	39.4	245	49-70
RT CLXL745	L	0.0	16.5	38.9	218	47-71
RT Gemini 214 CL	L	0.0	13.5	40.5	238	53-70
RT XL753	L	0.0	12.9	40.9	279	53-72
RT XL760	L	0.0	13.6	40.5	238	52-70
Thad	L	0.0	14.0	40.4	218	58-72
CL272	M	0.0	14.7	40.0	229	55-69
CLX1111	M	0.0	14.3	40.3	226	51-69
Jupiter	M	0.0	15.6	39.7	232	57-68
Titan	M	0.0	14.6	40.2	254	56-70
Mean	--	0.0	14.1	40.3	223	56-71
$LSD_{0.05}$[c]	--	NA[d]	1.6	1.0	17.5	7.3-1.6

[a] Grain length: L = long-grain; M = medium-grain.
[b] %HR-%TR = % head rice - % total white rice.
[c] LSD = Least significant difference.
[d] NA = not available.

Table 6. Results of Mississippi Co. Producer Rice Evaluation Program Trial during 2016.

Cultivar	Grain length[a]	Lodging	Moisture	Test weight	Grain yield	Milling yield[b]
		----------- (%)	----------	(lb/bu)	(bu/acre)	(%HR-%TR)
CL111	L	5.0	15.2	39.5	181	56-71
CL151	L	55.0	16.0	39.0	181	53-70
CL153	L	2.5	14.4	40.1	177	56-71
CL163	L	25.0	15.5	39.3	153	51-69
CL172	L	23.3	13.9	40.3	188	55-70
CLX1024	L	17.5	14.9	39.7	177	53-70
Diamond	L	2.5	15.7	39.2	197	51-70
LaKast	L	20.0	16.2	38.8	169	56-71
Mermentau	L	0.0	15.0	39.6	173	59-71
Roy J	L	0.0	15.2	39.4	201	55-71
RT 7311 CL	L	12.5	14.2	40.0	230	46-69
RT CLXL745	L	52.5	15.7	39.1	213	51-70
RT Gemini 214 CL	L	0.0	13.7	40.3	252	48-69
RT XL753	L	37.5	16.3	38.7	244	42-68
RT XL760	L	36.7	16.2	38.9	220	53-69
Thad	L	0.0	14.6	39.9	182	51-70
CL272	M	0.0	15.3	39.5	176	53-69
CLX1111	M	35.0	15.8	39.0	184	47-68
Jupiter	M	60.0	17.4	38.5	196	57-69
Titan	M	57.5	16.9	38.6	204	53-69
Mean	--	22.1	15.4	39.4	195	52-70
$LSD_{0.05}$[c]	--	35.2	NS[d]	NS	27.2	6.5-1.6

[a] Grain length: L = long-grain; M = medium-grain.
[b] %HR-%TR = % head rice - % total white rice.
[c] LSD = Least significant difference.
[d] NS = not significant.

Table 7. Results of Poinsett Co. Producer Rice Evaluation Program Trial during 2016.

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	40.7	162	50-69
CL151	L	50.0	15.7	39.6	193	47-70
CL153	L	7.5	14.0	40.7	199	52-70
CL163	L	0.0	16.0	39.2	177	56-70
CL172	L	0.0	14.9	40.0	195	53-69
CLX1024	L	15.0	14.5	40.2	179	44-67
Diamond	L	10.0	14.3	40.7	220	51-70
LaKast	L	17.5	14.9	40.2	208	43-69
Mermentau	L	0.0	15.8	39.5	183	57-70
Roy J	L	0.0	14.8	40.0	201	50-69
RT 7311 CL	L	0.0	13.8	40.6	249	41-68
RT CLXL745	L	12.5	15.2	39.9	215	43-69
RT Gemini 214 CL	L	20.0	14.4	40.3	247	45-68
RT XL753	L	0.0	13.3	41.0	250	38-69
RT XL760	L	25.0	13.7	40.9	233	48-69
Thad	L	0.0	14.3	40.5	188	53-69
CL272	M	0.0	14.6	40.2	211	33-67
CLX1111	M	10.0	15.2	39.8	220	27-67
Jupiter	M	0.0	14.1	40.7	236	48-67
Titan	M	0.0	15.1	40.0	240	33-67
Mean		8.4	14.6	40.2	210	46-69
$LSD_{0.05}$[c]	--	17.8	NS[d]	NS	13.5	3.9-0.9

[a] Grain length: L = long-grain; M = medium-grain.
[b] %HR-%TR = % head rice - % total white rice.
[c] LSD = Least significant difference.
[d] NS = not significant.

Table 8. Results of White Co. Producer Rice Evaluation Program Trial during 2016.

Cultivar	Grain length[a]	Lodging	Moisture	Test weight	Grain yield	Milling yield[b]
		----------- (%) ----------		(lb/bu)	(bu/acre)	(%HR-%TR)
CL111	L	0.0	18.1	38.0	118	60-72
CL151	L	57.5	19.9	37.3	158	60-71
CL153	L	0.0	18.4	38.1	148	64-72
CL163	L	0.0	18.2	38.2	109	60-71
CL172	L	0.0	19.0	37.7	150	62-72
CLX1024	L	0.0	16.2	39.0	109	61-72
Diamond	L	0.0	19.8	37.5	188	60-71
LaKast	L	0.0	16.1	39.1	137	50-71
Mermentau	L	0.0	19.7	37.5	146	63-72
Roy J	L	0.0	18.3	38.0	172	59-72
RT 7311 CL	L	7.5	19.0	37.5	211	57-71
RT CLXL745	L	12.5	17.0	38.6	192	58-72
RT Gemini 214 CL	L	0.0	20.0	37.0	206	60-71
RT XL753	L	0.0	16.7	38.8	235	56-71
RT XL760	L	7.5	17.8	38.1	190	58-71
Thad	L	0.0	19.2	37.6	117	61-71
CL272	M	0.0	21.8	36.7	152	56-69
CLX1111	M	0.0	18.9	37.6	177	56-69
Jupiter	M	0.0	21.0	37.1	176	62-69
Titan	M	0.0	18.7	38.2	168	54-69
Mean	--	4.3	18.7	37.9	163	59-71
$LSD_{0.05}$[c]	--	9.4	2.6	1.3	18.3	4.3-1.2

[a] Grain length: L = long-grain; M = medium-grain.
[b] %HR-%TR = % head rice - % total white rice.
[c] LSD = Least significant difference.

Table 9. Results of Woodruff Co. Producer Rice Evaluation Program Trial during 2016.

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	45.6	157	48-70
CL151	L	0.0	14.7	44.5	167	49-70
CL153	L	0.0	14.7	44.6	156	52-71
CL163	L	20.0	11.2	46.9	137	57-70
CL172	L	0.0	14.2	45.8	160	54-71
CLX1024	L	0.0	12.4	46.3	131	50-70
Diamond	L	0.0	13.8	45.9	167	39-69
LaKast	L	0.0	14.2	46.3	169	44-69
Mermentau	L	0.0	10.1	46.7	134	55-71
Roy J	L	0.0	13.1	46.1	157	41-69
RT 7311 CL	L	10.0	14.4	45.6	161	43-69
RT CLXL745	L	98.5	14.7	45.0	186	40-69
RT Gemini 214 CL	L	65.0	14.9	44.0	187	44-67
RT XL753	L	37.5	15.2	44.8	179	35-68
RT XL760	L	69.5	14.9	45.0	178	46-67
Thad	L	0.0	8.3	47.0	130	48-69
CL272	M	0.0	14.8	44.2	173	22-66
CLX1111	M	0.0	15.0	45.2	185	19-66
Jupiter	M	0.0	14.2	44.6	170	45-66
Titan	M	0.0	14.2	45.8	172	19-66
Mean	--	15.0	13.6	45.5	163	42-69
$LSD_{0.05}$[c]	--	16.4	1.6	1.0	18.1	5.9-1.7

[a] Grain length: L = long-grain; M = medium-grain.
[b] %HR-%TR = % head rice - % total white rice.
[c] LSD = Least significant difference.

Table 10. Rice cultivar reactions[a] to diseases (2016).

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	--	MS	R	--	--	MS	MR	--
Cheniere	S	MS	VS	MS	S	S	S	S	MR	MS
CL111	VS	MS	S	VS	S	VS	S	S	MS	S
CL151	S	VS	VS	VS	S	VS	S	S	S	S
CL153	S	MS	--	MS	S	--	S	S	MR	--
CL163	VS	S	--	MS	R	--	MS	--	MS	--
CL172	MS	MS	--	MS	S	--	MS	S	MR	--
CL272	S	MS	--	VS	S	--	MS	--	MR	S
Cocodrie	S	S	VS	S	S	VS	S	S	MR	S
Della-2	S	R	--	MS	MS	--	--	--	--	--
Diamond	S	S	--	MS	--	S	S	VS	MS	--
Francis	MS	VS	MR	VS	S	S	VS	S	MS	S
Jazzman	MS	MR	S	S	S	S	MS	S	MS	MS
Jazzman-2	S	MS	--	VS	S	--	S	S	--	--
JES	S	R	VS	S	R	VS	MS	MS	S	MR
Jupiter	S	S	S	MR	MR	VS	MS	MS	S	MR
LaKast	MS	S	MS	MS	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	R	S	VS	S	MR	MS
RT 7311 CL	MS	--	--	--	--	--	S	--	MS	--
RT CLXL729	MS	R	MS	MR	R	S	MS	S	S	S
RT CLXL745	S	R	R	MR	R	S	S	S	S	S
RT CLXP756	MS	--	--	--	--	--	--	S	--	S
RT Gemini 214 CL	S	--	--	--	--	--	MS	--	MS	--
RT XL723	MS	R	S	MR	MS	S	MS	S	MS	S
RT XL753	MS	R	MS	MR	R	--	MS	S	MS	S
RT XL760	MS	MR	--	MR	R	--	MS	VS	S	--

continued

Table 10. Continued.

Cultivar	Sheath blight	Blast	Straight-head	Bacterial panicle blight	Narrow brown leaf spot	Stem rot	Kernel smut	False smut	Lodging	Black sheath rot
Taggart	MS	MS	R	MS	MS	S	S	S	MS	MS
Thad	S	S	S	MS	-	-	S	VS	MR	-
Titan	S	MS	--	MS	--	--	MS	MS	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 grower fields across Arkansas and other rice states in southern U.S. In general, these ratings represent expected cultivar reactions to disease under conditions that most favor severe disease development.
Table prepared by Y. Wamishe, 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 2016 were: Diamond, Titan, and Horizon Ag's Clearfield CL153, CL163, CL172, and the CL272. Grain yields in the 2016 were typical of most years for the cultivars studied at the three locations, except for a few of the Clearfield cultivars at the University of Arkansas System Division of Agriculture's Northeast Research and Extension Center (NEREC) where weather may have played a role in reducing yields. The cultivars did not display their usual grain yield response to N fertilizer at the University of Arkansas System Division of Agriculture's Pine Tree Research Station (PTRS) due a ton of poultry litter applied prior to planting because the field was precision leveled during the winter months. Thus, the yields of most cultivars peaked at a much lower N fertilizer rate than is typical. This was the first year CL153 and CL272 were in the cultivar × N rate study and thus there is not enough data to make a recommendation at this time. The multiple years of results for Diamond, Titan, CL163, and CL172 indicate these cultivars should yield 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.

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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 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 2016 at three locations as follows: Arkansas entered the short stature, long-grain Diamond, and the semidwarf, medium-grain Titan; 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, the semidwarf, long-grain CL153 in cooperation with Louisiana, and the semidwarf, medium-grain CL272 in cooperation with Louisiana. Clearfield rice cultivars are tolerant to the broad-spectrum herbicide imazethapyr (Newpath).

Procedures

Locations where the cultivar × N fertilizer rate studies were conducted and corresponding soil series are as follows: University of Arkansas System Division of Agriculture's 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, treated with the urease inhibitor NBPT, on to a dry soil surface at the 4- to 5-leaf 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-leaf stage and within 2 days of preflood N-fertilization at all locations, except PTRS which took 4 days. The studies remained flooded until the rice was mature. At maturity, the center five 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 and mean separations were based upon protected least significant difference (P = 0.05) where appropriate (Tables 2-8).

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.

Grain yields in the 2016 cultivar × N rate studies were typical of most years for the cultivars studied at the three locations, except for a few of the Clearfield cultivars at the NEREC where weather may have played a role in reducing yields. The cultivars did not display their usual grain yield response to N fertilizer at the PTRS due a ton of poultry litter applied a couple of months prior to planting because the field was precision leveled during the winter months. Thus, the yields of most cultivars peaked at a much lower N fertilizer rate than is typical at PTRS. Pertinent agronomic information such as planting, herbicide, fertilization and flood dates are shown in Table 1.

Diamond achieved a grain yield of around 190 bu/acre on the clay soil at NEREC when 120 to 180 lb N/acre were applied preflood, but did not significantly increase in grain yield when more than 120 lb N/acre was applied (Table 2). There was a small amount of lodging at the NEREC when 180 or 210 lb N/acre were applied to Diamond and a tendency for grain yield to decrease as N rate became excessive. Diamond achieved grain yields over 200 bu/acre when grown on the silt loam soils at PTRS and RREC when 120 lb N/acre or more was applied preflood and was able to maintain these yields with no lodging when up to 180 lb/acre was applied. The grain yield of Diamond did not significantly increase when more than 150 lb N/acre was applied preflood at the RREC and when more than 90 lb N/acre was applied at the PTRS. The low amount of N fertilizer required to maximize yields at the PTRS is most certainly due to the ton of poultry litter that was applied a couple of months prior to planting because of the precision leveling over the previous winter. Similar to 2015 (Norman et al., 2016), Diamond exhibited a stable yield over a wide range of N rates with minimal lodging. After 2 years of study, it would appear Diamond has a stable yield over a wide range of N rates and should yield 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 maximum grain yield of 188 bu/acre when 120 or 150 lb N/acre were applied preflood on the clay soil at the NEREC (Table 3). Noticeable lodging of

Titan was observed as well as a tendency for the yields to decrease, similar to some other cultivars, when the preflood-N rate increased to 180 lb N/acre or more at the NEREC. Titan achieved a maximum grain yield of 197 bu/acre on the silt loam at the PTRS, but the grain yield of Titan did not significantly increase when more than 60 lb N/acre was applied preflood due to the ton of poultry litter that was applied a couple of months prior to planting. Even with all of that N from the poultry litter, Titan maintained a stable yield of over 190 bu/acre with no lodging at the PTRS when 60 to 180 lb N/acre was applied preflood. Somewhat similar to 2015 (Norman et al., 2016), Titan achieved a grain yield of 211 bu/acre on the silt loam soil at the RREC when 150 lb N/acre was applied preflood, but did not significantly increase in yield when greater than 120 lb N/acre was applied preflood. Lodging was not an issue for Titan at the PTRS or RREC locations in 2016. After 2 years of study it would appear Titan has a stable yield over a wide range of N rates and should yield 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.

CL153 did not significantly increase in grain yield when more than 90 lb N/acre was applied preflood on the clay soil at the NEREC (Table 4). For some reason CL153 did not yield well at the NEREC in 2016 with yields of only 152 to 160 bu/acre when 90 to 210 lb N/acre was applied. Some of the other Clearfield cultivars, CL163 and CL172, also did not yield well at the NEREC in 2016 and rainy weather during flowering and/or extremely hot conditions during early grain fill are believed to be possible causes. The poultry litter applied at PTRS resulted in CL153 not significantly increasing in grain yield when more than 90 lb N/acre was applied preflood at this location. CL153 reached a peak grain yield of 183 bu/acre when 150 lb N/acre was applied preflood on the silt loam soil at PTRS and CL153 displayed some lodging when the N rate was increased to 180 lb N /acre. On the silt loam soil at the RREC, CL153 achieved a maximum yield of 193 bu/acre when 180 lb N/acre was applied, but did not significantly increase in yield when more than 150 lb N/acre was applied preflood. This was the first year CL153 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.

Clearfield 163 did not significantly increase in grain yield when more than 90 lb N/acre was applied preflood on the clay soil at the NEREC and this is probably due to inclement weather as described for CL153 (Table 5). The grain yield of CL163 did not increase when more than 60 lb N/acre was applied to the silt loam soil at PTRS because of the poultry litter applied a couple of months prior to planting. Clearfield 163 displayed only slight lodging at the PTRS at the highest N rates even though a ton of poultry litter was applied preplant. Clearfield 163 achieved a maximum grain yield of 202 bu/acre on the silt loam soil at the RREC when 180 lb N/acre was applied preflood, but did not significantly increase in grain yield when greater than 150 lb N/acre was applied preflood which is similar to what was found in 2015 (Norman et al., 2016). After 3 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 90 lb N/acre was applied preflood on the clay soil at the NEREC (Table 6). CL172 only attained a maximum grain yield of 160 bu/acre at the NEREC due to inclement weather as was mentioned previously at this location. Grain yields of CL172 did not significantly increase at the PTRS when more than 60 lb N/acre was applied on the silt loam soil because of the poultry litter applied due to the precision leveling. CL172 reached a peak yield of 176 bu/acre at PTRS and had a yield range of 167 to 176 bu/acre when 60 to 180 lb N/acre was applied with no lodging. The yield of CL172 did not significantly increase at the RREC when more than 150 lb N/acre was applied preflood similar to what was observed in 2015 (Norman et al., 2016). CL172 obtained a maximum yield of 202 bu/acre when 180 lb N/acre was applied preflood on the silt loam soil at RREC. After 3 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 and does not appear to lodge easily. 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 yield of the medium-grain CL272 did not significantly increase when more than 120 lb N/acre was applied preflood on the clay soil at the NEREC (Table 7). CL272 attained a maximum grain yield of 188 bu/acre when 150 lb N/acre was applied preflood with no lodging at the NEREC. There was a small amount of lodging and a decrease in yield when the N rate was increased to 180 or 210 lb N/acre on this clay soil. Grain yields did not significantly increase at the PTRS when more than 60 lb N/acre was applied on the silt loam soil because of the poultry litter applied. CL272 reached a peak yield of 187 bu/acre at PTRS and had a yield range of 179 to 183 bu/acre when 90 to 150 lb N/acre was applied. The yield of CL272 did not significantly increase at the RREC when more than 150 lb N/acre was applied preflood. CL272 obtained a maximum yield of 193 bu/acre when 180 lb N/acre was applied preflood on the silt loam soil at RREC. This was the first year CL272 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 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 is able to estimate 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, Titan, CL153, CL163, CL172, and CL272. 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.

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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 2016.

Practices	NEREC	PTRS[a]	RREC
Preplant fertilizers	----	----	22 March 0-60-90 + 10 lb Zn as $ZnSO_4$
Planting date	25 April	11 May	23 April
Emergence date	11 May	19 May	1 May
Herbicide spray date and procedures	25 April 1.3 pt Command/acre + 40 oz Facet L/acre + 0.75 oz Permit Plus/acre	17 May 2.1 pt Prowl/acre + 3.2 oz League/acre	27 April 8 oz Command/acre + 20 oz Facet L/acre
Herbicide spray date and procedures	9 June 4 qt Propanil/acre	3 June 4 qt Propanil/acre	19 May 24 oz Facet L/acre + 1.0 oz Permit Plus/acre
Preflood N date	10 June	15 June	25 May
Flood date	12 June	19 June	26 May
Insecticide spray dates and procedures	----	----	15 July 2.5 oz Karate/acre
Drain date	26 August	8 September	25 August
Harvest date	14 September	29 September	13 September

[a] The field was precision leveled in the winter of 2016 and received 2000 lb/acre of poultry litter a couple of months prior to planting.

Table 2. Influence of nitrogen (N) fertilizer rate on the grain yield of Diamond rice at three locations during 2016.

	Grain yield		
N fertilizer rate	NEREC[a]	PTRS	RREC
(lb N/acre)	------------------------	(bu/acre)	------------------------
0	95	152	117
60	----	188	164
90	165	197	180
120	189	202	203
150	190	202	222
180	189 [5b]	204	223
210	175 [10]	----	----
$LSD_{0.05}$[c]	15.6	6.9	14.9

[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] Numbers in superscript to the side of the grain yield are lodging percentages.
[c] LSD = least significant difference.

Table 3. Influence of nitrogen (N) fertilizer rate on the grain yield of Titan rice at three locations during 2016.

	Grain yield		
N fertilizer rate	NEREC[a]	PTRS	RREC
(lb N/acre)	------------------------	(bu/acre)	------------------------
0	118	137	109
60	----	191	152
90	174	195	175
120	188	197	193
150	188 [3b]	196	211
180	174 [30]	196	202
210	178 [50]	----	----
$LSD_{0.05}$[c]	15.7	11.5	19.2

[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] Numbers in superscript to the side of the grain yield are lodging percentages.
[c] LSD = least significant difference.

Table 4. Influence of nitrogen (N) fertilizer rate on the grain yield of Clearfield CL153 rice at three locations during 2016.

	Grain yield		
N fertilizer rate	**NEREC[a]**	**PTRS**	**RREC**
(lb N/acre)	----------	**(bu/acre)**	----------
0	99	120	115
60	----	166	134
90	152	173	156
120	154	174	167
150	158	183	190
180	160	171 [15b]	198
210	155	----	----
$LSD_{0.05}$[c]	12.8	12.1	17.4

[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] Numbers in superscript to the side of the grain yield are lodging percentages.

[c] LSD = least significant difference.

Table 5. Influence of nitrogen (N) fertilizer rate on the grain yield of Clearfield CL163 rice at three locations during 2016.

	Grain yield		
N fertilizer rate	**NEREC[a]**	**PTRS**	**RREC**
(lb N/acre)	----------	**(bu/acre)**	----------
0	96	122	122
60	----	156	152
90	144	160	161
120	146	163 [3b]	179
150	145	155	186
180	138	144 [13]	202
210	122	----	----
$LSD_{0.05}$[c]	13.1	9.9	18.6

[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] Numbers in superscript to the side of the grain yield are lodging percentages.

[c] LSD = least significant difference.

Table 6. Influence of nitrogen (N) fertilizer rate on the grain yield of Clearfield CL172 rice at three locations during 2016.

	Grain yield		
N fertilizer rate	NEREC[a]	PTRS	RREC
(lb N/acre)	----------	(bu/acre)	----------
0	103	151	98
60	----	174	133
90	144	176	157
120	160	171	175
150	155	167	191
180	157	167	202
210	157	----	----
$LSD_{0.05}$[b]	17.4	6.7	13.1

[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 CL272 rice at three locations during 2016.

	Grain yield		
N fertilizer rate	NEREC[a]	PTRS	RREC
(lb N/acre)	----------	(bu/acre)	----------
0	101	160	54
60	----	176	119
90	168	183	139
120	176	187	164
150	188	179	181
180	177 [8b]	172	193
210	164 [13]	----	----
$LSD_{0.05}$[c]	12.4	19.2	16.5

[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] Numbers in superscript to the side of the grain yield are lodging percentages.

[c] LSD = least significant difference.

Table 8. Influence of nitrogen (N) fertilizer rate on the grain yield of Wells rice at three locations during 2016.

	Grain yield		
N fertilizer rate	**NEREC[a]**	**PTRS**	**RREC**
(lb N/acre)	------------------------	**(bu/acre)**	------------------------
0	89	148	75
60	----	169	120
90	149	175	140
120	174	177	154
150	183	181	181
180	183	173	191
210	168 [10b]	----	----
$LSD_{0.05}$[c]	21.1	12.6	16.6

[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] Numbers in superscript to the side of the grain yield are lodging percentages.

[c] LSD = least significant difference.

Preliminary Post-Flood-Release Nitrous Oxide Emissions from Rice as Affected by Cultivar and Water Management

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Abstract

Nitrous oxide (N_2O) is a greenhouse gas (GHG) and is a common byproduct of rice (*Oryza sativa* L.) production. Nitrous oxide emissions from agricultural fields are a concern due to the potency of N_2O in the atmosphere relative to other GHGs [i.e., carbon dioxide (CO_2) and methane (CH_4)] and the prevalence of cereal grain crops, such as rice, to the diet of the general population. The objective for this research was to determine if there is an influence by cultivar (i.e., pure-line and hybrid) and water management practice (i.e., full-season flood and intermittent flood) on N_2O emissions during the post-flood-release segment of the rice growing season on a silt loam soil in conjunction with a delayed-flood, direct-seeded production system. Research was conducted outside of Stuttgart, Ark., at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC) using polyvinyl chloride (PVC), vented, non-steady-state chambers for gas sampling. Gas samples were collected at 60-min time intervals (i.e., 0 and 60 min) on days 1, 2, 5, and 6 during post-flood-release. Gas samples were then analyzed using a Shimadzu GC-2014 ATFSPL 115V gas chromatograph with an electron capture detector (ECD). Numerically, the pure-line/full season flood treatment combination produced the largest post-flood-release N_2O emissions at 51.5 g N_2O-N/ha and the numerically lowest N_2O emissions were emitted by the hybrid/full-season flood treatment combination at 33.0 g N_2O-N/ha with the hybrid/intermittent flood and pure-line/intermittent flood treatment combinations having the second (43.9 g N_2O-N/ha) and third (39.2 g N_2O-N/ha) largest N_2O emissions, respectively. As differing rice production combinations (i.e., cultivar and water management practice) are being used for a multitude of reasons (i.e., increase grain yield, water usage reduction, etc.) it is important to know how these combinations may increase the current environmental concerns (GHG emissions) that arise from rice production in Arkansas and globally.

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Introduction

Rice (*Oryza sativa* L.) is a cereal grain that is vital to the health of the human population by supplying up to 25% of all energy received from food consumption (Maclean et al., 2013). With the human population expected to grow to over 9 billion by 2050, it can be expected that rice production will also have to increase to keep up with the growing population (UN-DESA, 2015).

Rice is typically grown under flooded soil conditions, which is unique when compared to other agronomically grown row crops, such as corn (*Zea mays* L.), soybean (*Glycine max* L. Merr.), or wheat (*Triticum aestivum* L.). Due to anaerobic conditions that results from the common flood-irrigated water management in rice production, rice fields are a source of greenhouse gas (GHG) emissions [i.e., methane (CH_4) and nitrous oxide (N_2O)].

Non-carbon-dioxide greenhouse gases (i.e., CH_4 and N_2O) from agricultural lands account for 8.3% of all GHG emissions in the U.S., and globally non-CO_2 emissions are expected to increase 36% by 2030 (Smith et al., 2014; USEPA, 2016b). Nitrous oxide is a GHG attributed to rice production with a potency 298 times greater than CO_2 in the atmosphere, and accounts for 59% all non-CO_2 emissions from agricultural fields (USEPA, 2016a,b). Recent studies have shown that between 0% and 82% of all N_2O emissions during the rice growing season occur after the flood is released and prior to harvest (Zou et al., 2005; Zhao et al., 2011; Adviento-Borbe et al., 2013, 2015). Nitrous oxide has the potential to be abundant during the post-flood-release period because the soil oxidation-reduction potential (Eh) is at a level during the flooded portion of the growing season that is not optimal (i.e., +280 to +220 mV) for N_2O production, but instead is optimal (i.e., +220 to -280 mV) for the production of other GHG such as CH_4 (Brady and Weil, 2008; Rogers et al., 2014).

Alternative water management practices, other than the conventional full-season flood, have the opportunity to affect the amount of N_2O emissions from irrigated rice fields. One alternative water management practice is the intermittent flooding of rice fields, which allows the flood to dissipate naturally through plant uptake, evaporation, transpiration, and vertical/lateral movement through the soil profile until a specific water potential is achieved and the flood is re-applied (Roberts et al., 2015). The oscillation between wet and dry soil conditions occurs several times during a growing season without significantly impacting yield (Roberts et al., 2015). This alternative water management practice has the potential to reduce water use and CH_4 emissions, but increase N_2O emissions during the flooded portion of the growing season due to the periodic influx of O_2 increasing the soil Eh to levels more suitable for N_2O production.

The objective of this field study was to evaluate the effects of cultivar (i.e., pureline and hybrid) and water management practice (i.e., full-season flood and intermittent flooding) on post-flood-release N_2O emissions from delayed-flood, direct-seeded rice production on silt loam soil. It was hypothesized that the potential increase in N_2O fluxes during the flooded portion of the growing season will likely result in lower N_2O emissions from the intermittent flood during the post-flood-release portion of the growing season compared to the full-season flood because a portion of the added fertilizer-N will already have been previously emitted.

Procedures

From May to October 2016, research was conducted at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC) east of Stuttgart in Arkansas County, Ark. The research area had been cropped for the last 15 years to a rice-soybean rotation on Dewitt silt-loam (Fine, smectitic, thermic Typic Albaqualfs) soil with < 1% slope (USDA-NRCS, 2013, 2014). The climate in the region is classified as Humid Subtropical (Arnfield, 2016). The average monthly air temperature is 61.7 °F (16.5 °C), with the largest average maximum air temperature of 91.9 °F (33.3 °C) in July, the mean annual precipitation is 49.2 inches (125.6 cm), with the most precipitation in April (5.3 in. or 13.4 cm), and the least precipitation in August (2.4 in. or 6.1 cm; NOAA-NCEI, 2010).

A randomized complete block (RCB) design, with four replications for each treatment combination (i.e., pure-line/full-season flood, hybrid/full-season flood, pure-line/intermittent flood, and hybrid/intermittent flood), was established with a factorial arrangement of field plots, where each plot was 5.25 ft (1.6 m) wide by 15 ft (4.6 m) long. To implement the full-season or intermittent flood scheme, bays were established adjacent to one another and separated by a levee with a total of 16 field plots in each bay. Rice was drill-seeded on 23 April 2016 with 7-in. (18-cm) row spacing. The pure-line, long-grain cultivar LaKast, developed at the RREC (Moldenhauer et al., 2014), and the hybrid, long-grain cultivar XL753 from RiceTec, Inc. (Houston, Texas) were planted in 9 rows in each plot.

The full-season-flood bay was managed with an approximate 10-cm deep flood between one month after planting (i.e., the 4- to 5-lf rice stage) and two weeks before harvest. The intermittent-flood bay had a management scheme where the soil was flooded to an approximate 10-cm depth to saturate the soil to a water potential of 0 kPa. Once the soil reached saturation, the flood water was allowed to dissipate (i.e., by evaporation, plant uptake, transpiration, and physical movement away from the soil surface) and the soil was allowed to dry down to a water potential of -20 kPa. Once the soil reached the -20 kPa water potential, the bay was reflooded and the process began again so that the bay oscillated between 0 kPa (i.e., saturation) and -20 kPa for the remainder of the growing season until the flood was release in preparation for harvest (Roberts et al., 2015).

A split application of nitrogen fertilizer occurred pre-flood and mid-season using N-(n-butyl) thiophosphoric triamide (NBPT)-coated urea (46-0-0) based on recommended fertilization rates for optimum yields in Arkansas. Pre-flood fertilization, which was applied manually to dry soil 1 day (8 June 2016) before the flood was established (9 June 2016), for the pure-line LaKast was 105 lb N/acre (118 kg N/ha) and was 120 lb N/acre (135 kg N/ha) for the hybrid XL753. Mid-season fertilizer-N was applied manually to flood water for LaKast (45 lb N/acre or 50.5 kg N/ha) at 24 DAF (27 June 2016), which was the beginning of internode elongation, and at 32 DAF (5 July 2016) for XL753 (30 lb N/acre or 33.6 kg N/ha).

Similar to Rogers et al. (2014) and Smartt et al. (2016), polyvinyl chloride (PVC) base collars 30-cm tall and 30-cm in diameter were inserted into the soil in each plot after initial fertilization during the flooding of the bays. The placement of the base collars were over two rows, which included an inter-row area of bare soil (Parkin and Venterea, 2010). The base collars have a beveled end with four 12.5-mm diameter holes placed 12 cm right above the end. The holes on the base collars were situated right above the soil surface when the base collars were inserted into the soil as to allow the floodwater to flow in and out of the base collar. Two days prior to post-flood-release gas sampling, collar extensions were place on base collars and left on until the day of biomass collection. When the holes in the base collar were exposed to the atmosphere, septa were inserted into the holes to prevent gas escaping during the sampling period. Wooden boardwalks were placed between field plots and over levees to assist in reducing soil disturbance during gas sampling.

A 10-cm tall, 30-cm diameter PVC cap with a rubber flap for connection was placed on top of an extension to create an enclosed-headspace chamber that trapped gases for sampling (Livingston and Hutchinson, 1995). Sampling took place between 930 and 1100 h, which was similar to the gas-sample timing in past studies (Adviento-Borbe et al., 2013; Rogers et al., 2014; Smartt et al., 2016). A 20-mL syringe, with a 0.5-mm × 25-mm needle [Beckton Dickson and Co (B-D), Franklin Lakes, N.J.], was inserted into a septa (part #73828A-RB, Voigt Global, Lawrence, Kan.) in the cap while on top the chamber to collect gas samples. Syringes were opened while inserted into the septa and, when removed from the septa, the contents of the syringes were transferred into a pre-capped (20-mm headspace crimp cap; part #5183-4479, Agilent Technologies, Santa Clara, Calif.) and pre-evacuated, 10-mL glass vials (part #5182-0838, Agilent Technologies, Santa Clara, Calif.).

Gas samples were collected the day prior to flood release (22 August 2016) and then four times after the flood was released, with additional sampling on the day after biomass removal (29 August 2016). Sampling occurred within a 60-min interval after the cap was sealed onto the chamber (i.e. 0 and 60 min after capping). After the last sample was collected, all the caps and extensions were removed until the next sampling date. The air temperature, relative humidity, and barometric pressure were measured before and after sampling.

Biomass was collected from within the base collar and from a 39.4-in. (1-m) length of row adjacent on the sixth day after flood release (23 August 2016). Biomass was dried at 131 °F (55 °C) for 3 weeks and weighed. Grain was then cleaned of the chaff from the 39.4-in. (1-m) biomass sample and a subsample was additionally dried at 158 °F (70 °C) for at least 48 h. Grain masses were corrected to 12% moisture content for yield expressed as lb/acre and kg/ha.)

Gas samples were stored at room temperature and were analyzed on a Shimadzu GC-2014 ATFSPL 115V gas chromatograph (Shimadzu North America/Shimadzu Scientific Instruments Inc., Columbia, Md.), using an electron capture detector (ECD) for N_2O detection. Before field samples were analyzed, gas standards were also collected in the laboratory for analysis and used as quality control. Nitrous oxide fluxes were determined based on the change in concentration in the chamber over the 60-min sampling interval (i.e., 0 and 60 min). The concentration at each interval (mL/L) was plotted against the time interval (min) to evaluate the change in concentration over time (Rogers et al., 2014; Smartt et al., 2016). Average post-flood-release N_2O emissions [i.e., 1 to 6 days after flood release (DAFR)], yield, and N_2O emissions per unit grain yield were calculated.

Results and Discussion

Nitrous Oxide Fluxes and End of Season Flood Release Emissions, and Rice Yields

Across all cultivar and water management treatment combinations (i.e., pure-line/full-season flood, hybrid/full-season flood, pure-line/intermittent flood, and hybrid/intermittent flood) there were no consistent trends in N_2O fluxes from 1 day prior to flood release (DPFR) to 7 DAFR (Fig. 1). Gas samples from the chambers 7 DAFR did not include any rice plants, as the plants were collected the day prior (6 DAFR). During the period of 1 DPFR to 6 DAFR, the majority of the treatment combinations numerically ranged from a maximum flux of 15.6 g N_2O-N/ha/ day (hybrid/intermittent flood) on 2 DAFR to a minimum flux of 0 g N_2O-N/ ha/day (hybrid/full-season flood) at 5 DAFR (Fig. 1). However, after the rice plants were removed, N_2O fluxes from all treatments 7 DAFR were approximately 3.0 N_2O-N/ha/day (Fig. 1).

Post-flood-release N_2O emissions were numerically similar between water management practices (i.e., full-season flood and intermittent flood). Averaged across cultivars, the full-season flood emitted 42.2 g N_2O-N/ha during the post-flood-release period, which was only 2% more than that produced from the intermittent flood (41.5 g N_2O-N/ha; Table 1). Averaged over water management, the pure-line cultivar LaKast had numerically larger post-flood-release N_2O emissions (45.4 g N_2O-N/ha) compared to the hybrid cultivar XL753 (38.4 g N_2O-N/ha). Mean post-flood-release N_2O emissions from the treatment combinations numerically ranked the following: LaKast/full-season flood (51.5 g N_2O-N/ha) > XL753/intermittent flood (43.9g N_2O-N/ha) > LaKast/intermittent flood (39.2 g N_2O-N/ha) > XL753/full-season flood (33.0 g N_2O-N/ha).

For the 2016 growing season, averaged over water management scheme, the hybrid XL753 (297 bu/acre; 15.0 Mg/ha) had a numerically greater yield than the pure-line cultivar LaKast (222 bu/acre; 11.2 Mg/ha; Table 1). However, averaged over cultivar, rice grain yields were more numerically similar between water management practices, with the full-season flood yielding 266 bu/acre (13.4 Mg/ha) and the intermittent flood yielding 253 bu/acre (12.8 Mg/ha). Among the treatment combinations, the hybrid/full-season flood (308 bu/acre; 15.6 mMg/ha) had the numerically largest yield, while the pure-line/intermittent flood had the numerically lowest yield (221 bu/acre; 11.1 Mg/ha).

The N_2O-emissions-to-yield ratio indicates that the full-season flood (3.34 g N_2O-N/Mg grain) and LaKast (4.04 g N_2O-N/Mg grain), averaged over the other respective treatment factor, had the numerically largest ratio meaning the largest N_2O emissions inefficiency (Table 1). However, among the treatment combinations, the pure-line/full-season flood (4.56 g N_2O-N/Mg grain) had the numerically largest emissions-to-yield ratio, while the hybrid/full-season flood (2.12 g N_2O-N/Mg grain) had the numerically smallest emissions-to-yield ratio. These results indicate that the hybrid/full-season flood treatment combination was the most efficient in terms of lowest N_2O emissions per unit grain yield produced.

Previous research has shown that N_2O emissions from the post-flood-release period of the rice growing season accounts for between a minimum of 0% to an estimated max of 82% of the total growing season N_2O emissions (Zou et al., 2005; Zhao et al., 2011; Adviento-Borbe et al., 2013, 2015). The lower end of the 0 to 82% range includes studies where no N fertilizer was used, a midseason drain was used, or the majority of N_2O emissions occurred before flood release and transplanting of rice plants (Zou et al., 2005; Zhao et al., 2011; Adviento-Borbe et al., 2013, 2015), while the mid to upper end of the range includes studies where excess N application or full-season flood was used (Zou et al., 2005; Pittelkow et al., 2013; Adviento-Borbe et al., 2015; Simmonds et al, 2015). The reported range in season-long N_2O emissions suggests that the post-flood-release emissions represents a median of 41% of the total season-long N_2O emissions. If extrapolated to the whole growing season, post-flood-release N_2O emissions measured in this study would result in season-long N_2O emissions that are comparable to season-long N_2O emissions measured in full-season flood on a silt loam soil in Arkansas (Adviento-Borbe et al., 2013; Simmonds et al., 2015) and drill-seeded rice production in an intermittent-flood-type production system in California (LaHue et al., 2016).

Significance of Findings

The hybrid cultivar under intermittent flooding had total post-flood-release N_2O emissions that were the second largest emissions compared to all other treatment combinations, while the hybrid under full-season flooding had, on average, the lowest numerical post-flood-release N_2O emissions. The opposite trend occurred for the pure-line under full-season flood, which had the numerically largest N_2O emissions compared to all treatments, with the pure-line under intermittent flood having the second to lowest post-flood-release N_2O emissions. These results indicate that the hybrid/intermittent flood and pure-line/full-season flood treatment combinations may exacerbate N_2O emissions, in which N_2O is 298 times more potent as a GHG than CO_2 is in the atmosphere (USEPA, 2016a). Consequently, these findings warrant further study of common agronomic practice effects on N_2O emissions.

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Table 1. Mean post-flood-release nitrous oxide (N_2O) emissions, yield, and N_2O emissions per unit grain yield by cultivar [pure-line LaKast and hybrid XL753 (n = 8)], water management practice [full-season flood and intermittent flood (n = 8)], and cultivar/water management practice treatment combination (n = 4).

Treatment	N_2O emissions	Rice yield	Rice yield	Emissions: yield ratio
	(g N_2O-N/ha)	(bu/acre)	(kg/ha)	(g N_2O-N/Mg grain)
LaKast/Intermittent flood	39.2 (12.4)[a]	221	11149	3.51
XL753/Intermittent flood	43.9 (18.1)	285	14377	3.05
LaKast/Full-season flood	51.5 (11.4)	224	11289	4.56
XL753/Full-season flood	33.0 (11.5)	308	15570	2.12
Intermittent flood	41.5 (10.2)	253	12763	3.28
Full-Season flood	42.2 (8.3)	266	13429	3.34
LaKast	45.4 (8.1)	222	11219	4.04
XL753	38.4 (10.2)	297	14973	2.58

[a] Numbers in parentheses represent the standard error.

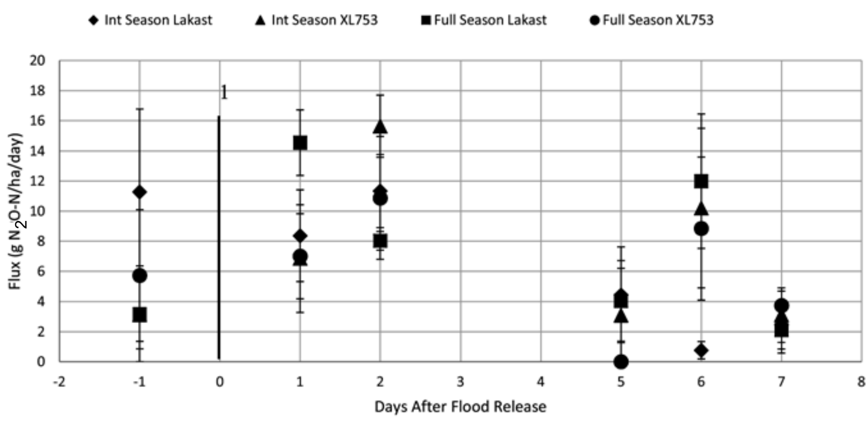

Fig. 1. Average (+/- standard error; n = 4) post-flood-release nitrous oxide (N_2O) fluxes for cultivar (i.e., LaKast or XL753) and water management practice [i.e., full-season flood (Full Season) or intermittent flood (Int Season)] treatment combinations. The solid vertical line (1) indicates the timing of flood release for both treatment bays.

Rice Yield Response to Delayed Preflood Nitrogen Application and Flood Establishment Time

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Abstract

Soil moisture conditions at the time of preflood nitrogen (N) application influence how efficiently rice (*Oryza sativa* L.) can take up and utilize applied urea-N. The time at which preflood N is applied may sometimes be delayed to obtain the desired dry soil conditions for urea application. Our research objective was to determine how long preflood urea N-fertilizer application and flood establishment timing can be delayed before grain yield loss occurs on selected rice cultivars. Two trials were conducted in 2016 that included four or five rice cultivars, five urea-N rates, and six or seven fertilization and flooding dates. Fertilization dates ranged from 11 May to 6 July that were associated with Degree-Day 50 (DD50) unit accumulations ranging from 227 to 1843. For this report, only grain yield results from rice receiving 160 lb urea-N/acre will be presented since this treatment usually maximized grain yield. The date that rice reached 50% heading was delayed by 0.68 days for each day that N fertilization was delayed. The 2016 results showed rice grain yields were generally greatest when rice was fertilized before 800 DD50 units were accumulated. The current recommendation for preflood fertilizer-N and flood establishment appears to be a safe general guideline. How long fertilization and flooding can be delayed appears to be cultivar specific and dependent upon other management practices being implemented properly.

Introduction

In Arkansas, 96% of the rice area is seeded using a direct-seeded, delayed-flood system (Hardke, 2015). Applying urea-N to dry soil conditions delays and reduces ammonia (NH_3) volatilization and nitrification, allowing rice to maximize fertilizer-N uptake. The preflood urea-N fertilizer application and flood establishment time is

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sometimes delayed due to moist field conditions in order to obtain dry soil conditions. Very little research has been conducted on the topic of delaying preflood N-applications. Research on this topic is limited to work conducted in the early 1990s using long-season cultivars where the flood was delayed 21 days beyond the 5-leaf growth stage (Norman et al., 1992). How long preflood N can be delayed has been a recent topic of interest due to the use of short-season cultivars, limited irrigation water availability, and, during recent years, untimely rains that have caused frequent moist field conditions at the recommended time to apply preflood fertilizer-N.

We currently use the Degree-Day 50 (DD50) program as an aid to predict key rice growth stages and guide selected management practices. The recommended optimum time to apply preflood N is 350-550 DD50 units. If moist field conditions are present, the current recommendation suggests delaying the preflood urea-N application until the soil is dry or until 3 weeks before the predicted date that rice will reach the 0.5-in. internode elongation stage (Hardke et al., 2013). The objective of this project was to evaluate how long the preflood N and flood establishment can be delayed before grain yield loss occurs.

Procedures

In 2016, two experiments were established on silt loam soils; a Dewitt silt loam (fine, smectitic, thermic Typic Albaqualf) at the University of Arkansas System Division of Agriculture's Rice Research Extension Center (RREC) near Stuttgart, Ark., and a Calhoun silt loam (fine-silty, mixed, active, thermic Typic Glossaqualf) at the University of Arkansas System Division of Agriculture's Pine Tree Research Station (PTRS) near Colt, Ark. Rice was seeded on 5 April and emerged 22 April at the PTRS. At the RREC, rice was seeded on 23 April and emerged 1 May. Management practices followed the University of Arkansas System Division of Agriculture recommendations, except for preflood fertilizer N-application and flood establishment. Weed control differed between sites and among fertilization timings within sites since we did not want yield potential of later flood times to be influenced by factors other than the fertilizer N-timing treatments being used.

The PTRS study contained 4 cultivars including CL111, LaKast, Roy J, and Jupiter; the RREC study contained 5 cultivars including CL111, LaKast, RiceTec (RT) XL753, Roy J, and Jupiter. All seed was treated with CruiserMaxx and each cultivar was drill-seeded in plots 9 rows wide and 16 feet long. At the PTRS, rice was drill-seeded at an average rate of 80 lb/acre. At the RREC, all rice was seeded using a cone planter with conventional cultivars seeded at 30 seed/ft^2 and the hybrid rice, RTXL753, was seeded at 10 seed/ft^2. Row spacing was 7 in. at the RREC and 7.5 in. at PTRS. Each cultivar was represented within individual levees and the levees were flooded in a sequential order to represent different N fertilization and flood times. The PTRS study had 7 N fertilization and flood dates and the RREC study had 6 N fertilization and flood dates, which are summarized in Table 1.

Urea N-rates ranged from 0 to 160 lb urea-N/acre in 40 lb N/acre increments. Urea was treated with the urease inhibitor n-(n-butyl) thiophosphoric thriamide (Agrotain

Ultra 3 qt/ton urea) and applied on the dates listed in Table 1. Application timings were intended to be 7 days apart, however, untimely rainfall sometimes caused deviation from the plan to get the preflood N out on dry soil conditions. Although all N rates were harvested, this report will summarize only rice grain yield response to 160 lb urea-N/acre.

Rice heading notes were taken weekly during reproductive growth to determine how maturity was affected by delaying preflood N-application and flood establishment. Plots were visually rated from 0% to 100%, with 0% meaning no visible panicles and 100% meaning all plants had a visible panicle. Plots were harvested with a small-plot combine after the rice reached maturity. Grain yield was adjusted to 12% moisture for statistical analysis.

The experiment was a randomized complete block design. Each N fertilization time was a block with every cultivar and N rate represented in each block and replicated four times. The average date of 50% heading was calculated by cultivar for rice fertilized with 160 lb urea-N/acre at each flood time. Yield data for rice fertilized with 160 lb N/acre were subjected to analysis of variance (ANOVA), analyzed by cultivar with fertilization date as the only fixed effect, and, when appropriate, flood-time yield means were separated using Fisher's protected least significant difference test ($P = 0.05$).

Results and Discussion

The rate at which rice matured differed among N rates (not shown), cultivar, and the time at which preflood N-fertilization and flooding were performed. All cultivars showed similar maturity trends, but for simplicity purposes, only the average dates of 50% heading for Roy J fertilized with 160 lb urea-N/acre are shown (Tables 2 and 3). Fifty percent heading was delayed by 32 days at the PTRS when preflood N-application and flooding was delayed from 11 May to 6 July (Table 2) and delayed 33 days when preflood N-fertilizer application and flooding was delayed from 12 May to 29 June (Table 3). On average, the date of 50% heading for rice fertilized with 160 lb urea-N/acre was delayed 0.68 days for each day N fertilization and flooding was delayed.

The grain yield of all rice cultivars seeded at the PTRS was affected by preflood urea N-application time and the trend among N fertilization times was similar for all four cultivars (Table 2). The highest numerical yield was produced by rice flooded at the 5-lf stage (second flood time) and it was statistically similar to the yield of rice flooded at the 3-lf stage (first flood time) for all cultivars except Roy J. Fertilization and flooding after the accumulation of 1600 DD50 units (the last two flood times, 5-lf + 28 or 35 days) resulted in substantial yield reductions with yields being only 26% (Roy J) to 64% (CL111 and Jupiter) of the highest yield produced. The medium-grain Jupiter appeared to hold its yield potential longer in the absence of N and flooding than the long-grain cultivars in this trial. Yields for rice flooded on the third (5-lf + 7 days) through the fifth timings (5-lf + 21 days) tended to be intermediate (69% to 93% of maximum) and variable among the cultivars and suggested possible environmental interactions (e.g., heat) with the timing of key growth stages (e.g., flowering). Overall, the results from the 160 lb N/acre rate at the PTRS indicated that yields were maximized when preflood N-fertilization and flooding were performed before 555 DD50 units, and tended to decline as fertilization was delayed. It should be noted that the number of accumulated DD50 units had exceeded the current recommendation for applying preflood N by the June 8 N application time.

At the RREC, grain yields were generally maximized when preflood N-fertilization and flooding were performed by the time 640 DD50 units were accumulated, but some cultivars (LaKast and RTXL753) maintained statistically maximal yields until N was applied as late as 858 DD50 units (Table 3). Similar to the PTRS, the last flood time, 1492 DD50 units, resulted in significantly lower yields for all cultivars compared to the fertilization time that produced maximum yield. Jupiter and the RTXL753 appeared to retain their yield potential longer than the three conventional long-grain cultivars. Although not statistically compared between sites, Roy J behaved differently at the RREC where yield potential was among the lowest of all cultivars but the decline in yield across N fertilization times was relatively subtle. At the PTRS, the yield potential of Roy J was comparable to the other long-grain cultivars, but the yield loss from delayed N fertilization was greater than all other cultivars.

Significance of Findings

The results from two trials conducted in 2016 with multiple cultivars and N fertilization/flood timings indicate that rice maturity and grain yield are affected by delaying preflood N-application and flooding and that cultivars may respond differently. The current recommended optimum time to apply preflood urea-N is 350 and 550 DD50 units with the absolute latest application time being no later than 510 DD50 units before the predicted date of 0.5 inch internode elongation. Based on this recommendation, the DD50 predicted absolute deadline for preflood N-application ranged from 620 DD50 units (shortest duration) for CL111 to 895 DD50 units (longest duration) for Jupiter. Results from the two research sites indicate maximum grain yield was produced when preflood urea-N was applied during the currently recommended optimum time. Significant yield losses were associated with delaying fertilization beyond 800 DD50 units suggesting the current recommendation developed with older cultivars may be accurate. A new, robust recommendation that is safe for most production environments and cultivars can be developed only when all data and site years are assessed using regression analysis to more accurately predict yield response across time. These are preliminary results and producers are encouraged to follow the current University of Arkansas System Division of Agriculture recommendations.

Acknowledgments

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Table 1. Dates of seeding, emergence, and preflood urea-N application for two research sites in 2016. The values in parentheses indicate the number of accumulated Degree-Day 50 (DD50) units for each urea-N application time.

Site[†]	Seeding date	Emergence date	Urea-N applied[‡] Time 1	Time 2	Time 3	Time 4	Time 5	Time 6	Time 7
			month/day (cumulative DD50 units)						
PTRS	04/05	04/22	05/11 (368)	05/23 (555)	06/08 (966)	06/15 (1183)	06/22 (1404)	06/29 (1625)	07/06 (1843)
RREC	04/23	05/01	05/12 (227)	05/23 (403)	06/01 (640)	06/09 (858)	06/20 (1205)	06/29 (1492)	----

[†] RREC = Rice Research and Extension Center; PTRS = Pine Tree Research Station.
[‡] Flood establishment occurred 1 day after N fertilizer application at RREC and 3 days after N fertilizer application at PTRS.

Table 2. Rice grain yield and maturity as affected by seven different dates of preflood urea-N (160 lb/acre) application and corresponding cumulative DD50 units of four cultivars seeded on 5 April 2016 at the Pine Tree Research Station, near Colt, Ark.

Fertilization time		50% Heading date	Grain yield			
Date	DD50 units	Roy J	CL111	Jupiter	LaKast	Roy J
		(days after emergence)	(bu/acre)			
11 May	368	91	156 BA[†]	199 B	201 AB	180 B
23 May	555	93	169 A	218 A	207 A	198 A
8 June	966	100	145 BC	192 CB	192 B	138 D
15 June	1183	109	125 DE	187 CB	164 C	159 C
22 June	1404	114	131 CD	186 C	157 C	136 D
29 June	1625	123	111 EF	185 C	133 D	90 E
6 July	1843	123	109 F	141 C	123 D	51 F
$LSD_{(0.05)}$[‡]			15	13	11	14
P-value			<0.0001	<0.0001	<0.0001	<0.0001

[†] Means within a column followed by a different letter are significantly different at the $P = 0.05$ level.
[‡] LSD = least significant difference.

Table 3. Rice grain yield and maturity as affected by six different dates of preflood urea-N (160 lb/acre) application and corresponding cumulative Degree-Day 50 (DD50) units of five rice cultivars seeded on 23 April 2016 at the Rice Research Extension Center, near Stuttgart, Ark.

Fertilization time		50% Heading date	Grain yield				
Date	DD50 units	Roy J	CL111	Jupiter	LaKast	Roy J	RTXL753
		(days after emergence)	(bu/acre)				
12 May	227	83	190 A[†]	194 A	194 A	177 A	237 AB
23 May	403	86	174 B	187 A	190 A	157 BC	227 BC
1 June	640	89	185 AB	190 A	194 A	169 AB	249 A
9 June	858	97	152 C	174 B	183 AB	158 BC	242 A
20 June	1205	112	147 C	194 A	175 B	164 ABC	228 BC
29 June	1492	116	124 D	168 B	140 C	151 C	222
$LSD_{(0.05)}$[‡]			14	12	14	15	13
P-value			<0.0001	0.0019	<0.0001	0.0336	0.0027

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

[‡] LSD = least significant difference.

Summary of Crop Yield and Soil-Test Potassium Responses to Long-Term Potassium Fertilization

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Abstract

Long-term fertilization trials that assess the cumulative effects of different fertilization strategies across time allow scientists to develop effective fertilization practices and assess how these practices influence soil nutrient availability. The objective of this report is to summarize the 16-year history of the long-term, small-plot trials established in 2000 at the University of Arkansas System Division of Agriculture's Pine Tree Research Station (PTRS) near Colt, Ark. A long-term field trial was established on a Calhoun silt loam and cropped to a 1:1 rice-soybean rotation with annual K-fertilization rates of 0, 30-40, 60-80, 90-120 and 120-160 lb K_2O/acre/year. Application of only the highest potassium (K) rate has maintained the soil-test K above the initial value of 81 ppm in 2000. The mean soil-test K values from samples collected in January 2016 averaged 41, 46, 53, 71, and 81 ppm K for the 0, 30-40, 60-80, 90-120, and 120-160 lb K_2O/acre annual-K rates, respectively. Application of 90-120 or 120-160 lb K_2O/acre/yr have produced maximal (98% to 100% of maximum) rice and soybean yields. Omitting K from a fertilization program for silt loam soils resulted in 16-year average yield losses of 37 bu rice and 16 bu soybean/acre. Although the lowest (40 lb K_2O/acre) annual K-fertilization rate resulted in significant yield losses, application of 40 lb K_2O/acre/yr produced the greatest yield increase per unit of fertilizer added (0.53 bu rice and 0.25 bu soybean/lb K_2O). These results provide convincing evidence to support K fertilization as a critical component to crop management that allows rice and soybean to maximize use of other crop inputs.

Introduction

The average percentage of modern crop yields attributed to fertilizer nutrient management in the U.S. is reported to be 40% to 60% (Stewart et al., 2005). Among

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crop management practices, nutrient management is unique in that farmers collect soil samples on which nutrient availability is assessed and used to predict what nutrients and how much of each are needed to prevent nutrient deficiency from limiting crop yield. Most other crop inputs are implemented based on scouting and the presence or risk of pest infestation. The development of soil-test methods that are well correlated with soil nutrient availability and calibrated to provide reasonably accurate phosphorus- (P) and K-fertilization rates is essential for responsible nutrient management. Precision nutrient management and the pursuit of ultra-high crop yields have resulted in numerous questions that range from whether university nutrient recommendations are sufficient for sustainable crop production to whether the application of high fertilizer rates to build soil nutrient levels is economically sustainable, especially on rented or leased fields.

During the past 20 years, we have aggressively researched rice response to P and K fertilization (Slaton et al., 2009) and continuously seek to assess the accuracy of fertilizer recommendations using short-term fertilizer rate trials (Fryer, 2015). Early in this process, we recognized the value of developing long-term fertilization trials that could assess the cumulative effects of different fertilization strategies across time and have reported the annual results of these long-term research trials. The objective of this report is to summarize the 16-year history of the long-term, small-plot K rate trials established at the University of Arkansas System Division of Agriculture's Pine Tree Research Station that were established in 2000. The focus of this report will be on rice and soybean yield and soil-test K trends across time.

Procedures

A long-term field trial was established at the PTRS in 2000 on a Calhoun silt loam and cropped to a 1:1 rice-soybean rotation with rice grown in the even numbered years and soybean grown in odd numbered years. Individual plots measure 25-ft wide and 16-ft long, which allows four passes with a 9-row drill (7.5-in. row spacing for rice and 7.5- to 15.0-in. spacing for soybean). The plots were conventionally tilled before establishment in 2000, but have been managed with no-tillage in 14 of the past 16 years. The same K-fertilizer treatments have been applied to each plot since the trial was initiated with applications made to the soil surface as early as February (preplant) to immediately following planting. From 2000-2006, the K rates were 0, 30, 60, 90 and 120 lb K_2O/acre/year applied as muriate of potash (KCl). In 2006, the rates were increased to increments of 40 (e.g., 0-160 lb) K_2O/acre/year.

Zinc, P, nitrogen (N, applied only to rice), and boron (B, applied only to soybean) have been applied uniformly across all plots and in ample amounts to ensure no-yield limitation from these essential nutrients. Management of rice and soybean with respect to stand establishment, pest control, irrigation, and other practices have closely followed University of Arkansas System Division of Agriculture's Cooperative Extension Service guidelines for full-season soybean and direct-seeded, delayed-flood rice production. At maturity, plots were trimmed, length was measured, and the middle rows were harvested with a small-plot combine. Grain weights and moistures were determined by hand and used to adjust grain yields to 12% (rice) or 13% (soybean) moisture by weight for statistical analysis.

Composite soil samples (0- to 4-in. depth) were collected from each plot immediately before the trial was started and each subsequent year in mid to late winter (January to March). Soil samples were oven-dried at 150 °F (65 °C), crushed, soil water pH was determined in a 1:2 soil weight-water volume mixture, extracted using the Mehlich-3 method, and elemental concentrations were determined by inductively coupled plasma atomic emission spectroscopy. Selected soil chemical property means are listed in Table 1.

The experiment was a randomized complete block (RCB) design with eight blocks that contained each K-fertilization rate. The mean annual soil-test K for blocks 1-4 and 5-8 were calculated for each year since 2000 and regressed using a linear model across time to indicate the long-term response of Mehlich-3 extractable K to K-fertilization rate using the REG procedure of SAS v. 9.4 (SAS Institute, Inc., Cary, N.C.). Analysis of variance was performed by crop with the MIXED procedure in SAS with significant differences interpreted when $P < 0.10$. Mean separations were performed using Fisher's protected least significant difference test. To examine the effect of K rate on the yield of each crop, year was considered a random effect. To show how crop response to K rate has changed across time, the actual yields were changed to percentage of mean yield and plotted by crop for each year without statistical analysis.

Results and Discussion

The mean soil properties in the research area have changed considerably during the past 16 years with notable increases in soil pH and Mehlich-3 extractable P, Ca, Mg, S and Zn (Table 1). The numerical increases in soil-test P and Zn are from fertilization to ensure that rice and soybean growth are not limited by these elements on the alkaline soil. The substantial increases in soil pH, Ca, and Mg are likely due to the long-term use of ground water high in calcium bicarbonate from the alluvial aquifer for irrigation.

Sixteen years of applying the five K-fertilization rates to the same research plots has had a substantial and somewhat surprising influence on soil-test K (Fig. 1). The average soil-test K in the top 4 inches of soil at the time the trial was started averaged 81 ppm. After 16-years of cropping and fertilization, application of only the highest K rate has maintained the soil-test K at or above the initial value. The mean soil-test K values from samples collected in January 2016 averaged 41, 46, 53, 71, and 81 ppm K for the 0, 30-40, 60-80, 90-120, and 120-160 lb K_2O/acre annual-K rates, respectively. The annual soil-test K means for soil receiving no K-fertilization are shown in Fig. 1 to highlight the extreme temporal variability in soil-test K. In consecutive years the mean soil-test K change has ranged from -48 (decrease between years) to 0 (no change), to +22 ppm (increase between years) in soil receiving no K-fertilizer. The pattern of fluctuation is the same for soil that has received each of the annual-K rates indicating the cause for the fluctuation is independent of fertilization. The massive fluctuations in soil-test K highlight the need to monitor grid or field values across time and how difficult, perhaps futile, it is to strive to build soil-test K via heavy fertilization to what is considered optimal values. These data suggest that the Calhoun soil is capable of fixing the K, K is lost via leaching or runoff, or both.

The overall average yields for nine rice crops and eight soybean crops increase numerically with each incremental increase in K-fertilizer (Table 2). Application of 90-120 to 120-160 lb K_2O/acre/y have produced maximal (98-100% of maximum) rice and soybean yields and with 60-80 lb K_2O/acre/y producing intermediate yields that are within 5% of the maximum numerical yield. These data show that omitting K from a fertilization program for silt loam soils can have dramatic long-term effects on yield with overall yield losses up to 37 bu rice and 16 bu soybean/acre. Although reducing the annual K-fertilization rate to 30-40 lb K_2O/acre resulted in significant yield losses compared to the maximum yield, it produced the greatest yield return per unit of K added (yield difference between each incremental K rate divided by the current incremental K rate of 40 lb K_2O/acre). For example, application of 40 lb K_2O/acre/y produced a yield increase of 0.53 bu rice and 0.25 bu soybean/lb K_2O. The yield return per unit of K fertilizer added declined as K rate increased for both rice (0.35, 0.28, and 0.23 bu/lb K_2O) and soybean (0.15, 0.13, and 0.10 bu/lb K_2O).

Rice and soybean yield response within each year will not be fully examined in this report but it is important to mention that at the onset of the experiment, yield differences among annual-K rates were either small or not significantly different during the first few years of the experiment (Figs. 2 and 3). The magnitude of yield differences between the annual-K rate producing the lowest and highest yields has become larger and predictable. During the experiment's last two-year crop cycle (2014-2015) the numerical difference between the lowest and greatest rice (2014) and soybean (2015) yields was 67 and 23 bu/acre, respectively.

Significance of Findings

Sixteen years of applying five different K-fertilization rates and cropping rice and soybean on a Calhoun silt loam that started with a low soil-test K (81 ppm) have resulted in substantial yield differences among annual-K rates with maximal yields produced by applying 90-120 to 120-160 lb K_2O/acre. Application of lower annual-K rates resulted in lost yield potential and caused soil-test K to decline across time despite the fact that K removal by harvested crop grain averaged from 39 to 51 lb K_2O/acre/y. This information suggests that fertilization using the checkbook method does not maintain soil-test K and fertilization should be based on calibration curves to maximize crop yields or economic returns. Maintaining and/or building soil-test K by aggressive fertilization programs beyond the rates that maximize crop yields may not be economically feasible. These results provide convincing evidence to support K fertilization as a critical component to crop management that allows rice and soybean to maximize use of other crop nutrients, irrigation, genetic potential, and pest management inputs to produce high crop yields.

Acknowledgments

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Fees administered by the Soil Test Review Board, and the University of Arkansas System Division of Agriculture.

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Table 1. Selected soil (0- to 4-in. depth) chemical property means (n = 8) from the no K-fertilizer control for the initial soil properties (2000) and the subsequent properties after two crop rotation cycles.

Year	pH	P	Ca	Mg	S	Zn
		----------	----------	(ppm)	----------	----------
2000	6.8	17	1370	273	3	1.5
2004	7.8	19	1695	311	8	3.5
2008	7.7	26	2083	374	11	5.9
2012	7.8	30	2196	400	14	10.9
2016	8.2	34	2808	462	18	10.5

Table 2. Summary of the rice (mean of 9 crops) and soybean (mean of 8 crops) yields averaged across crop years as affected by K-fertilizer rate on a Calhoun silt loam soil at the Pine Tree Research Station.

	Mean crop yield			
Annual K rate	Rice	Relative yield	Soybean	Relative yield
(lb K_2O/acre)	(bu/acre)	(% of maximum)	(bu/acre)	(% of maximum)
0	139 c†	79	46 c	74
30-40	160 b	91	56 b	90
60-80	167 ab	95	58 b	94
90-120	172 a	98	61 a	98
120-160	176 a	100	62 a	100

† Means in a column followed by the same letter are not statistically different ($P > 0.10$).

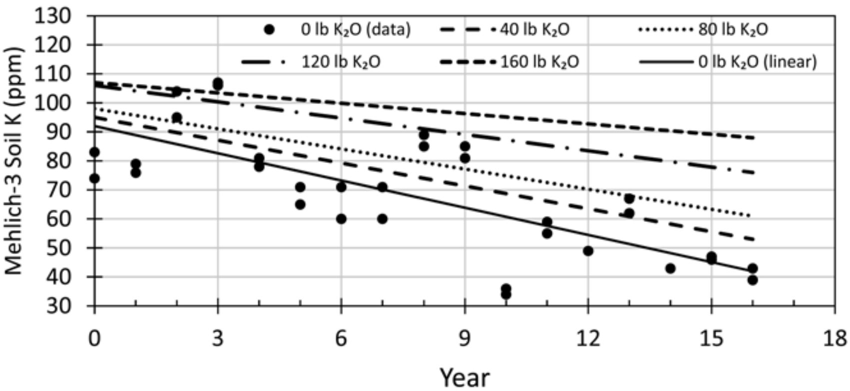

Fig. 1. Mehlich-3 extractable soil K response to annual K-fertilization rate across 16 years. The horizontal (at 81 ppm) solid gray line represents the average soil-test K at the start of the experiment. The filled, round symbols represent the two actual means (each the mean of 4 reps) for soil that received no K-fertilizer. For all other annual-K rates (40-160 lb K_2O/acre) only the trend line is given as predicted from data points.

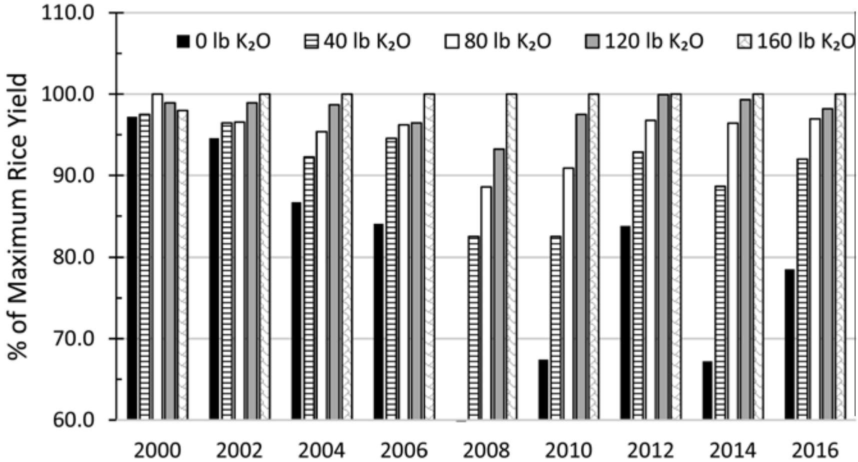

Fig. 2. The percentage of maximum rice yield as affected by annual K-fertilization rate for each individual year rice was grown.

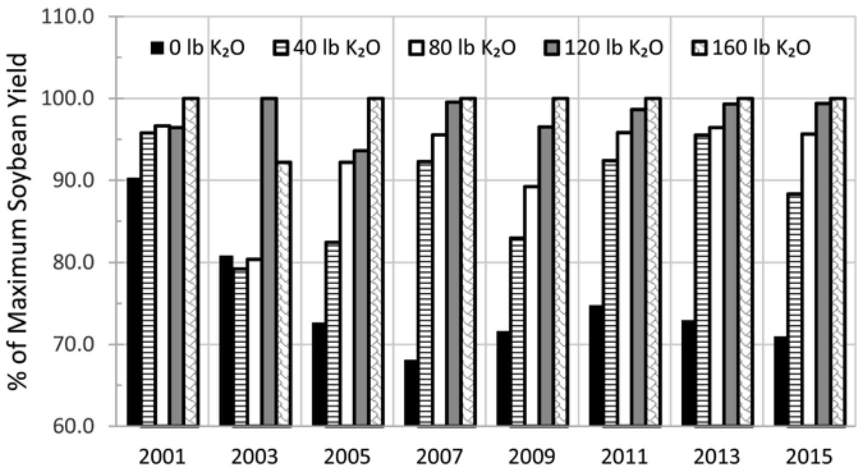

Fig. 3. The percentage of maximum soybean yield as affected by annual K-fertilization rate for each individual year soybean was grown.

Summary of Nitrogen Soil Test for Rice (N-STaR) Nitrogen Recommendations in Arkansas During 2016

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Abstract

Seeking to fine tune nitrogen (N) fertilizer rates, 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-fertilizer rates. First developed in 2010, Roberts et al. (2011) correlated direct steam distillation (DSD) results from 18-in. 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-in. 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 for the 2016 growing year, samples were categorized by county and soil texture. Samples were received from 176 fields across 19 Arkansas counties, with Mississippi county and Arkansas county submitting the largest number of fields, 91 and 25 fields, respectively. The total samples received were from 78 silt loam fields and 98 clay fields. The N-STaR N-rate recommendations for these samples were then compared to the producer's estimated N rate, the 2016 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. Each comparison was divided into three categories based on a decrease in N-fertilizer rate recommendation, no change in recommended N rate, or an increase in the N-rate recommendation. County, much like in 2013, 2014 and 2015, was a significant factor when N-STaR called for an increased ($P < 0.05$) or decreased ($P < 0.01$) N-fertilizer rate in the producer's estimated rate or cultivar recommendation comparison, but was only significant ($P < 0.001$) with a decreased N STaR N-rate recommendation in the standard recommendation comparison suggesting that some areas of the state may have higher or lower residual-N not accounted for in the other N-rate recommendation strategies when compared to N-STaR. Soil texture

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was a significant factor where N-STaR proposed decreased N rates in the cultivar ($P < 0.001$) and standard rate ($P < 0.01$) comparisons, but was only significant ($P < 0.05$) in fields in which N-STaR revealed a N-fertilizer rate increase in the producer's estimated N-rate comparison.

Introduction

Traditionally, N 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). University scientists correlated several years of plant-available soil N estimates from direct steam distillation (DSD) results obtained from 18-in. depth soil samples, equivalent to the 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 N mineralization rate and one of the highest N use efficiencies of any cropping system, therefore lending itself to a high correlation of mineralizable-N to 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 System Division of Agriculture's N-STaR Soil Testing Lab in Fayetteville, Ark. Later, researchers correlated DSD results from 12-in. depth soil samples to N response trials on clay soils (Fulford et al., 2013), and N-STaR rate recommendations became available for clay soils in 2013. Some Arkansas farmers are benefiting from this research by using N-STaR's field-specific N fertilizer rates, but many continue to depend on soil texture, cultivar, or routine management habits to guide N-rate decisions which may not always be the most profitable or environmentally sound practice.

Procedures

In an effort to summarize the effect of the N-STaR program in Arkansas, samples submitted to the N-STaR Soil Testing Lab for the 2016 growing year 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 supplied on the N-STaR Soil Test Laboratory Soil Sample Information Sheet, the 2016 Recommended Nitrogen Rates and Distribution for Rice Cultivars in Arkansas (Roberts and Hardke, 2016), 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 13 (SAS Institute, Inc., Cary, N.C.) with means separated using Fisher's least significant difference test ($P = 0.05$).

Results and Discussion

Samples were received from 176 fields which represented 30 farmers across 19 Arkansas counties. Mississippi county and Arkansas county, ranked 12th and 6th in planted acres (USDA-FSA, 2016), evaluated the largest number of fields, with 91 and 25 fields, respectively. Three other counties, Clay, Jackson, and Poinsett, sent in samples for more than 10 fields while the remaining counties submitted samples for less than five fields. Few samples were received by the N-STaR Soil Testing Laboratory in the post-harvest fall months when soil sampling conditions would have been more favorable, while the majority of samples were received during the typically wetter months of March and April. The samples received were from 78 silt loam fields and 98 clay fields (Table 1). Seven farmers sent samples for more than five fields while 18 farmers sent samples for just one field. One farmer submitted samples for 91 fields bringing the average number of samples submitted by farmer to 9.72 fields. There were nine farmers who submitted samples in 2015 that also submitted samples in 2016.

Planted rice acreage across Arkansas did slightly increase to approximately 1.513 million acres in 2016 (USDA-FSA, 2016) from the approximately 1.306 million acres in 2015 when excessive rains at critical planting times prevented many farmers from getting into the field (Hardke, 2016). N-STaR sample submission for 2016 mirrored the same trend increasing the number of submitted fields from the 118 fields in 2015. Just as in previous years, sample submission by county did not reflect the planted acre estimates for 2016 with Poinsett and Jackson counties having the highest estimates (USDA-FSA, 2016) yet only submitting samples for 12 fields each.

County and soil texture were found to be significant factors ($P < 0.001$) in the fields with a decrease in N rate when the N-STaR recommendation was compared to Arkansas' standard N-rate recommendation of 150 lb N/acre for silt loam soils and 180 lb N/acre for clay soils. This suggests that some 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-fertilizer 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 159 fields (90% of the 176 fields submitted) with an average decrease of 37.5 lb N/acre. No change in N recommendation was found for six fields, while 11 fields had an increase in N recommendation (6.25%), with an average increase of 8.6 lb N/acre.

Seventeen 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-rate recommendation for 74 fields (46.5% of the submitted fields) with an average decrease of 30.5 lb N/acre (Table 1). No change in N-rate recommendation was found for 12 fields, while 73 fields had an increase in N-rate recommendation (45.9%), with an average increase of 20.7 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 decreased 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 textures. N-STaR recommendations continue to be largely dependent on proper sampling depth for the respective soil texture and the farmer's correct classification of his field. County was found to be a significant factor in fields that showed a decrease ($P < 0.0001$) and an increase ($P < 0.05$) in N-rate recommendation in this comparison (Table 2).

When the N-STaR recommendation was compared to the 2016 Recommended Nitrogen Rates and Distribution for Rice Cultivars in Arkansas, 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 rates determined by N-STaR. Fourteen fields were excluded from this comparison—eight fields failed to include cultivar on the N-STaR Sample Submission Sheet while six fields listed two cultivars, Diamond and XP 4523, which were not included in the 2016 Recommended Nitrogen Rates and Distribution for Rice Cultivars in Arkansas. There was a decrease in the N-fertilizer rate recommendation for 142 fields (87.7% of the 162 fields) with an average decrease of 35.8 lb N/acre (Table 3). No change in N-rate recommendation was found for three fields, while 17 fields had an increase in N-rate recommendation (10.5%), with an average increase of 12.1 lb N/acre. County ($P < 0.05$) and soil texture ($P < 0.005$) were significant factors in the fields exhibiting a decreased N-STaR recommended rate, yet only soil texture ($P < 0.05$) was significant when N-STaR called for an increased rate suggesting that N rates for some cultivars may be overestimated for certain areas of the state or soil textures.

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 fertilization and cultivar recommendations will continue to be good ballparks for N rates, but field-specific N rates continue to offer the best estimate of needed N, regardless of 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 2016 Recommended Nitrogen Rates and Distribution for Rice Cultivars in Arkansas based on soil texture.

Soil texture	Number of fields submitted	Decreased N-STaR recommendation		Increased N-STaR[a] recommendation		No change in recommendation
		No. of fields	Mean N decrease	No. of fields	Mean N increase	
			(lb N/acre)		(lb N/acre)	
Standard soil texture						
Clay	98	96	42.6	---	---	2
Silt loam	78	63	29.7	11	8.6	4
Total	176	159	37.5	11	8.6	6
Producer estimate						
Clay	96	36	35.3	52	23.0	8
Silt loam	63	38	26.0	21	15.0	4
Total	159	74	30.5	73	20.7	12
Cultivar						
Clay	97	91	41.9	4	12.5	2
Silt loam	65	51	24.8	13	11.9	1
Total	162	142	35.8	17	12.1	3

[a] N-STaR = Nitrogen Soil Test for Rice.

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	Decreased N-STaR recommendation		Increased N-STaR recommendation		No change in recommendation
		No. of fields	Mean N decrease	No. of fields	Mean N increase	
			(lb N/acre)		(lb N/acre)	
Arkansas	16	14	33.1	1	5.0	1
Ashley	1	---	---	1	15.0	---
Chicot	1	1	85.0	---	---	---
Clay	14	11	20.9	2	15.0	1
Cross	3	3	73.3	---	---	---
Desha	1	---	---	1	5.0	---
Greene	3	---	---	3	8.3	---
Jackson	12	2	20	7	12.9	3
Lawrence	1	1	40	---	---	---
Mississippi	91	28	27.5	56	23.4	7
Phillips	1	1	5.0	---	---	---
Poinsett	12	11	30.0	1	25	---
Prairie	1	1	35.0	---	---	---
White	2	1	40.0	1	5	---
Total	159	74	30.5	73	20.7	12

[a] Seventeen fields did not list an estimated N rate on their Nitrogen Soil Test for Rice (N-STaR) Sample Submission Sheet and were excluded from the analysis.

Table 3. Distribution and change in nitrogen (N) fertilizer rate compared to the 2016 Recommended Nitrogen Rates and Distribution for Rice Cultivars in Arkansas by cultivar[a].

Soil texture	Number of fields submitted	Decreased N-STaR recommendation		Increased N-STaR recommendation		No change in recommendation
		No. of fields	Mean N decrease	No. of fields	Mean N increase	
			(lb N/acre)		(lb N/acre)	
Caffey	1	1	75.0	---	---	---
CL 151	11	8	19.4	2	32.5	1
CL 163	4	4	31.3	---	---	---
CLXL 745	10	7	30	3	11.7	---
Francis	1	1	80	---	---	---
Jupiter	9	8	49.8	1	10.0	---
LaKast	2	2	72.5	---	---	---
Roy J	13	7	27.9	5	11.0	1
Taggart	1	1	15.0	---	---	---
Wells	1	---	---	1	5.0	---
XL 723	2	2	25.0	---	---	---
XL 753	107	101	35.9	5	7.0	1
Total	162	142	35.8	17	12.1	3

[a] Eight fields did not list a cultivar on their Nitrogen Soil Test for Rice (N-STaR) Sample Submission Sheet and were excluded from the analysis. Six fields were submitted with a cultivar that was not included on the 2016 Recommended Nitrogen Rates and Distribution for Rice Cultivars in Arkansas and were also excluded from this comparison.

Fig. 1. Total Number of fields submitted with percent and mean decrease and increase in Nitrogen Soil Test for Rice (N-STaR) recommendation (lb N/acre) by county compared to the standard N-fertilizer rate recommendation.

Assessment of Natural-Air In-Bin Drying Strategies for Rough Rice in the United States Mid-South

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Abstract

There is a critical need to determine conditions that ensure successful natural-air, in-bin drying of rough rice. The objective for this study was to perform computer simulations using mathematical models to determine the impacts of natural-air, in-bin drying strategy on rough rice drying duration, maximum dry matter loss (DML), and percent overdrying. A 20-year weather data set (1995 to 2014) of ambient air temperature and relative humidity of U.S. mid-South rice growing locations (Jonesboro, West Memphis, and Stuttgart, Arkansas, and Greenville and Tunica, Mississippi) were procured. Drying simulations were performed using airflow rates 0.5 to 2 cfm/bu (0.69 to 2.77 m^3/min/ton), drying-start dates of 15 August to 15 October, and rough rice initial moisture contents (MCs) of 16% to 22% (wet basis, w.b.). Results showed that rough rice drying duration, dry matter loss, and percent overdrying were dependent on selected drying strategy with fan control strategy, initial rough rice MC, and airflow rate being key factors.

Introduction

Incomplete drying of rough rice, especially in top layers inside on-farm, natural-air (NA) drying bins, may predispose the rice to excessive respiration leading to increased mold growth, potential risks of mycotoxin development, and overall rice quality deterioration (Cnossen and Siebenmorgen, 2000; Richard et al., 2003; Belefant-Miller, 2009). In practice, the duration required to achieve complete drying of the rice is greatly affected by factors such as prevailing local weather conditions, initial moisture contents (IMC) of rough rice placed in the bins, drying airflow rate, fan control strategy, drying-start date, and bin configuration. Typically, producers do not have much control of the prevailing weather conditions. Therefore, depending on the local weather conditions, to achieve successful drying, it is important that the other factors that affect drying are controlled with certain limits, herein referred to as drying strategy. Otherwise, improper selection of NA drying strategy may cause rice quality deterioration and mycotoxin

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contamination with negative socioeconomic consequences to producers and consumers (Phillips et al., 1988).

Mathematical simulations hold potential to predict critical limits of the controllable factors involved during NA, in-bin drying of rough rice. The simulations help to determine the feasibility of successful rough rice drying for a given drying strategy and geographical location. Hence, the simulations accord the potential to make intelligent decisions on appropriate drying strategy without necessarily running field experiments.

The objectives for this study were as follows: (1) perform simulations to determine the effective fan control strategy to dry rough rice on-farm, at different rice-growing locations in the U.S. mid-South, and (2) determine the impacts of rough rice IMC, drying-start date, airflow rate, and fan control strategy on rice drying duration, maximum dry matter loss (DML), and percent overdrying.

Procedures

A software program, Post-Harvest Aeration Simulation Tool (PHAST), based on the Thompson equilibrium moisture content (EMC) model (Bartosik and Maier, 2004), was modified for simulation of NA, in-bin drying and storage of rough rice. Simulations were performed to evaluate implications of three fan control strategies comprising continuous NA (CNA), running the fan at set windows of drying air [EMC-controlled air (EMC-NA), and EMC-controlled air with supplemental heat (EMC-H)]. For each fan control strategy, rough rice at four IMC levels (16%, 18%, 20% and 22%) were dried at four air flow rates of 0.5, 1, 1.5, and 2 cfm/bu (0.69, 1.39, 2.08, and 2.77 m^3/min/ton) and drying-start dates of 15 August, 15 September, and 15 October. The simulations were performed using weather from representative rice-growing locations in the mid-Southern region of the U.S. (Jonesboro, West Memphis, and Stuttgart, Ark., and Greenville and Tunica, Mississippi). Twenty-year weather data (1995 to 2014) of hourly ambient air temperature and relative humidity (RH) were procured from accuweather.com (AccuWeather, Inc., State College, Pa.) for simulation purposes. Table 1 illustrates the simulation design carried out for this research.

For simulation purposes, rough rice depth within a bin was divided into 20 thin layers; the depth of rough rice in the bin was assumed to be 20 ft (6.10 m) which implied that each layer of rough rice had a thickness of 1.02 ft (0.31 m). It was assumed that the drying air and the rough rice within each layer reached temperature and MC equilibria within a specified time step (10 min). The energy and moisture balance applied to a thin layer of rough rice was determined as described by Jindal and Siebenmorgen (1994). Each simulation was run for 90 days or stopped earlier if the top layer of rough rice dried to MC of 14%. Each simulation provided outputs of the drying duration and final rough rice maximum DML, average rice MC, maximum MC, and minimum MC. The percent overdrying was determined by calculating the percentage of the number of rice layers in the grain bin that would dry to MC below 12% out of 20 layers. Dry matter loss was calculated based on the DML equation by Seib et al. (1980):

$$DML = 1 - exp[-At^{B}\, exp(C(T - 15.6) + D(M - 0.14))] \qquad \text{Eq. 1}$$

where, *DML* is dry matter loss, decimal; *t* is storage duration, h/1000; *T* is temperature, °C; *M* is moisture content, wet basis, decimal; and *A, B, C,* and *D* are constants of the equation. The constants used for the DML equations for long-grain rough rice (A = 0.00189, B = 0.654, C = 0.068, and D = 33.61) were adopted from Seib et al. (1980).

For EMC-H fan control strategy, fan operation was switched off when both the plenum air EMC and bottom-layer rough rice MC were less than the set EMC low limit, or the heater would be switched on when both the plenum air EMC and the bottom layer rough rice MC were greater than the set EMC high limit. For both EMC-H and EMC-NA fan control strategies, the set EMC high limit was one percentage point MC greater than the targeted EMC (Eq. 2), and a dynamic EMC low limit was used (Eq. 3). The fan-operation window narrowed as the rough rice MC approached the targeted EMC:

$$EMC_{high\ limit} = EMC_{targeted} + 1 \qquad \text{Eq. 2}$$

$$EMC_{low\ limit} = EMC_{targeted} - ((MC_{average} - MC_{bottom})\ /2) \qquad \text{Eq. 3}$$

where, $EMC_{high\ limit}$ is the highest limit of the targeted EMC in percentage, wet basis; $EMC_{targeted}$ is the targeted EMC in percentage, wet basis; $EMC_{low\ limit}$ is the lowest limit of the targeted EMC in percentage, wet basis; MC_{bottom} is bottom layer MC in percentage wet basis; and $MC_{average}$ is average MC in percentage, wet basis.

Statistical analyses 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. Bars were constructed using 1 standard deviation from the mean.

Results and Discussion

For each type of fan control strategy, rough rice with higher MC required longer drying duration; the higher the air flow rate, the shorter the drying duration (Fig. 1). The results show that operating EMC-H fan control strategy resulted in the shortest drying duration while EMC-NA fan control strategy had the longest drying duration; the drying duration increased when the rough rice drying started late in the year. The EMC-NA fan control strategy had the largest drying duration difference between different drying-start dates followed by CNA strategy, and EMC-H fan control strategy showed a small difference between different drying-start dates. The reason was that EMC-NA and CNA fan control strategies were largely dependent on the weather conditions. The EMC-H fan control strategy allowed lowering the air EMC using a heater, thereby lengthening the window of drying duration in a day.

For each type of fan control strategy, the rough rice with higher IMC suffered higher maximum DML, and the higher air flow rate reduced the maximum DML of rice in the bin. The maximum DML of rice for different drying-start dates is shown in Fig. 2. The maximum DML decreased when the drying started later in the year under the same air flow rate, IMC, and fan control strategy. The reason could be that temperature plays a paramount role in the DML equation (Eq. 1) as expressed by Seib et al. (1980).

Generally, temperature of air drops as winter approaches, and the respiration rates of rough rice and microorganism on rough rice drops as well; rough rice maintains lower

DML when temperature is lower. Therefore, rough rice maximum DML was inversely related to drying-start date. Also, DML in excess of 0.5% indicates the quality of rough rice depreciated and thus reduced grade value (USDA-FGIS, 1994). The rough rice with maximum DML could be found on the top layer of the drying bed which remains at high rough rice MC for longer duration than the bottom layers.

The large standard deviations (SDs) of drying duration or maximum DML for each data in Figs. 1 and 2 were caused by yearly and geographic weather differences. Assuming the result is a normal distribution, 68.3% of values lie within one SD above or below the mean. For each fan control strategy, comparing SDs of drying duration and maximum DML between different drying strategy combinations, the magnitudes of SDs of drying duration or maximum DML and magnitudes of drying duration or maximum DML were directly related, respectively. For instance, similar to drying duration, SDs also decreased when IMC decreased, or air flow rate increased. Comparing the overall SDs of drying duration and maximum DML for different fan control strategies, the EMC-H fan control strategy resulted in much smaller SDs compared to the other two fan control strategies and led to smaller differences in the SDs between different IMCs, drying-start dates, and air flow rates. In general, the variation in drying duration and maximum DML resulted from yearly and geographic weather differences; EMC-H fan control strategy showed the highest resistance to the weather difference compared to CNA and EMC-NA fan control strategies.

The effects of the studied drying strategies on minimum, maximum, and average final rough rice MC and percent overdrying of rough rice are shown in Fig. 3. Based on the simulations, the feasibility to dry rough rice successfully, to the target MC, becomes questionable as the drying-start date delays from 15 August to 15 October, the airflow rate reduces from 2.0 to 0.5 cfm/bu (2.77 to 0.69 m^3/min/ton), and rough rice IMC increases from 16% to 22%, especially for EMC-NA fan control strategy (Fig. 3). For a normal distribution, there are about 32% of values lying outside of one SD above or below the mean. Thus, if the upper error bar of drying duration exceed 90 days, it indicates that top layer rough rice had at least 16% chance of not being able to dry completely, and the maximum final MC and possibly the average final MC of rough rice would exceed 14%. For example, rough rice with 20% or 22% IMC was not dried successfully when the drying started from 15 October using EMC-NA fan control strategy at airflow rate of 0.5 cfm/bu (0.69 m^3/min/ton) as both average and maximum final MCs exceeded 14% (Fig. 3a), and upper error bars of drying duration exceeded 90 days (Fig. 1c). However, when CNA strategy was used, although upper error bars of drying duration were below 90 days in studied conditions (Fig. 1), Fig. 3 showed that all maximum final MCs were above 14% MC except in some cases when airflow rate was 2 cfm/bu (2.77 m^3/min/ton); in some extreme cases, average final MCs were also above 14%. In the studied simulations, termination of the drying was executed when the top layer rough rice MC was 14% or after 90 days of drying. Evidently, the top layer rough rice MC was not the maximum final MC in the drying bed when CNA strategy was used. The reason for choosing top layer rough rice MC to execute termination of simulation, instead of the highest MC layer of the whole rice bed, was because rice producers traditionally recognize that the drying operation would be completed when the top layer rough rice MC is lower than 14%. However, in actual practice, there is a possibility that air with high EMC may rewet the middle layer to exceed 14% MC when running fans continuously, as observed in the simulation results. Without the "cabling and sensing system" installed in the bin, rice producers have no way to find out the MC of each layer within the rice bed; this may be hazardous in terms of maintaining rice quality across the entire rice bed.

In the simulations, the target average MC of rough rice was set at 13% to represent what the rice industry considers to be the safe short-term storage MC for rough rice (IRRI, 2010). The lower limit of rough rice MC (12%) was set to take into account the need to avoid shrinkage related costs, which bear negative economic consequences to producers. High overdrying was observed in the rice bed for conditions with fans operated under CNA strategy (Fig. 3). In some drying cases using CNA fan control strategy, the minimum final MC was larger than 12%, but the percent overdrying was larger than zero. For example, when rough rice with 22% IMC was dried from 15 August using CNA strategy at airflow rate of 1 cfm/bu (1.39 m^3/min/ton), the resulting minimum final MC was 12.4% and the percent overdrying was 8.6%. This could be explained by the fact that the minimum final MCs and percent overdrying represent average of data obtained after individual simulations which used a total of 20 years (1995-2014) of weather data at five locations.

For EMC-NA or EMC-H fan control strategies, when both the bottom layer rough rice MC and plenum air EMC are above the set EMC high limit (14% MC), the control system would stop the fan operation or turn on the heater, respectively. Therefore, once a layer in the rice bed is dried below 14% MC, the layer cannot be rewetted to exceed 14% MC. Thus, the top layer rough rice has the maximum final MC in the bin and is the last layer to dry to 14% MC. Also, the fan-operation window narrows as the rough rice MC approaches the targeted EMC (Eq. 3). For EMC-H and EMC-NA fan control strategies, the fan operation stops when both the bottom layer rough rice MC and plenum air EMC are less than the set EMC low limit; air which could overdry the rough rice is not permitted into the bin through the rice when the average rough rice MC is close to the targeted MC. Therefore, percent overdryings were nearly zero for all studied conditions when the fan was operated under the EMC-H and EMC-NA strategies (Fig. 3).

In general, EMC-H fan control strategy for in-bin drying of rough rice had the fastest drying rate, low percent overdrying, and high resistance to yearly and geographic weather differences (i.e. compared to other two fan control strategies); therefore, the drying duration and maximum DML were relatively consistent year by year. EMC-NA fan control strategy resulted in slower drying rate, low percent overdrying, and lower resistance to yearly and geographic weather differences; therefore, the drying duration and maximum DML varied year by year. Compared to EMC-NA fan control strategy, using CNA fan control strategy would be slightly faster and have slightly better weather resistance in terms of drying duration and maximum DML; however, the CNA may bear three disadvantages: (1) high percent overdrying, (2) negative quality impacts caused by rice overdrying and rewetting, and (3) potential safety concerns of mold growth leading to formation of mycotoxin. Figure 4 illustrates the critical operation ranges for various drying strategies that will limit rice drying within one month while maintaining maximum DML and percent overdrying equal to or lower than 0.5% and 10%, respectively.

Significance of Findings

The simulations provided useful information to guide rice producers to achieve successful drying of rough rice with NA. The information may be useful to guide decisions on harvesting, drying, and storage conditions to maintain rice quality and prevent mycotoxin contamination.

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Table 1. Simulation design for assessment of implications of natural-air, in-bin drying strategies for rough rice in the U.S mid-South.

Fan control strategy[a]	Air flow rate[b]	Initial moisture content	Drying start date	Simulation year	Drying location
	(m^3/min/ton)	(%, wet basis)			
CNA	0.69 (= 0.5 cfm/bu)	16	15 Aug.	1995 to 2014	Jonesboro, Ark.
EMC-NA	1.39 (= 1 cfm/bu)	18	15 Sept.		West Memphis, Ark.
EMC-H	2.08 (= 1.5 cfm/bu)	20	15 Oct.		Tunica, Miss.
	2.77 (= 2 cfm/bu)	22			Stuttgart, Ark. Greenville, Miss.

[a] CNA = continuous natural-air fan control strategy; EMC-NA = equilibrium moisture content controlled natural air fan control strategy; EMC-H = equilibrium moisture content controlled air with supplemental heat fan control strategy.

[b] cfm/bu represents cubic feet per minute per bushel; m^3/min/ton represents cubic meter per minute per ton.

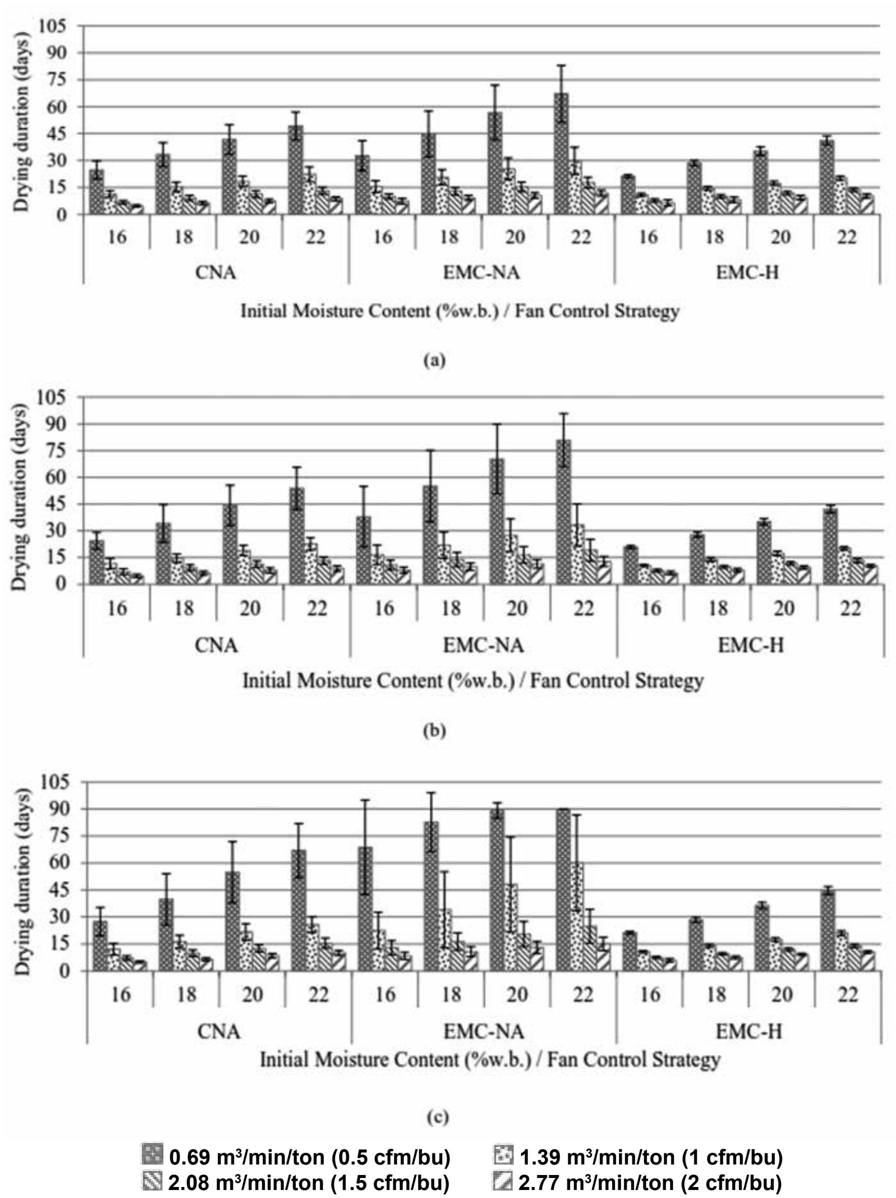


Fig. 1. Effect of initial moisture content (% wet basis, w.b.), fan control strategy (CNA, EMC-NA, and EMC-H), air flow rate, and drying-start date [(a) 15 August, (b) 15 September, and (c) 15 October] on rough rice drying duration. CNA = continuous natural-air fan control strategy; EMC-NA = equilibrium moisture content controlled natural-air fan control strategy; EMC-H = Equilibrium moisture content controlled air with supplemental heat fan control strategy. Each error bar was constructed using 1 standard deviation from the mean.

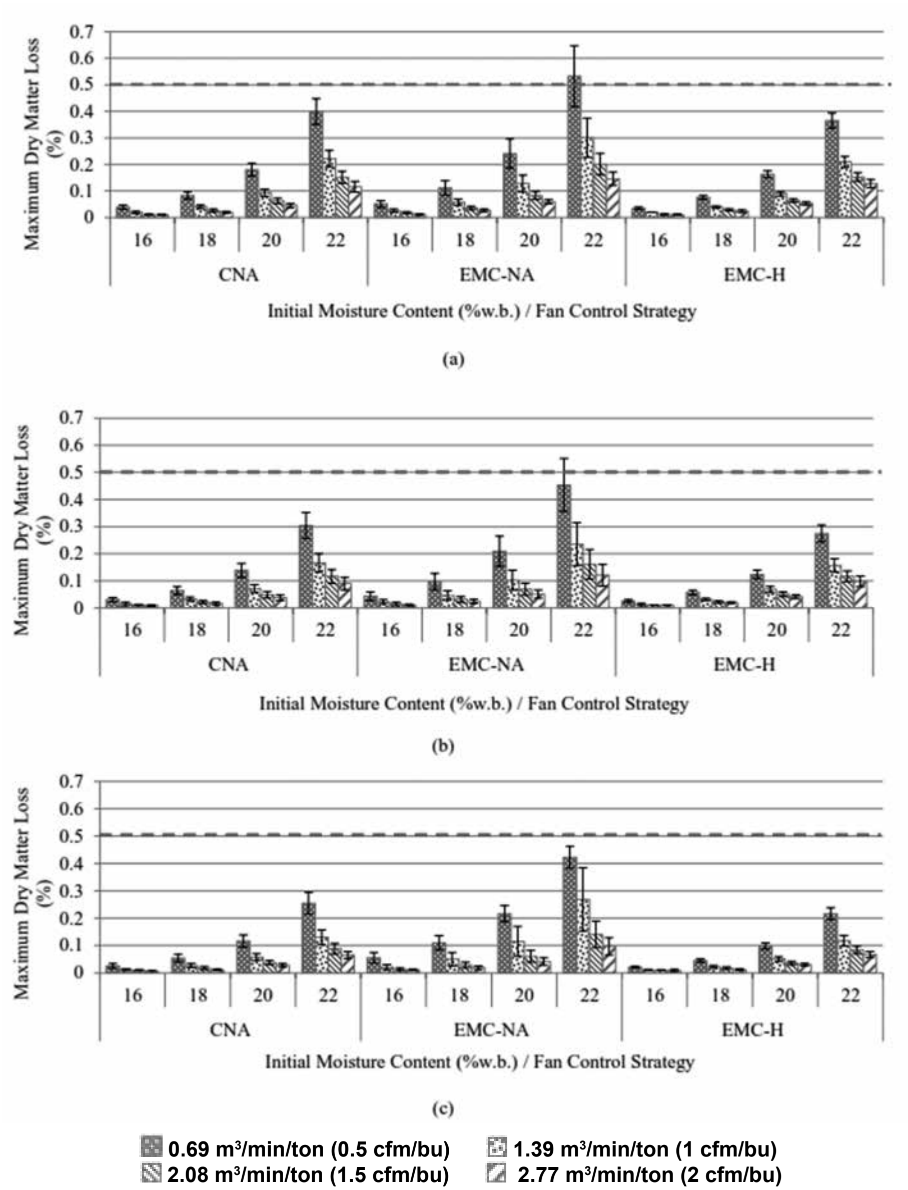
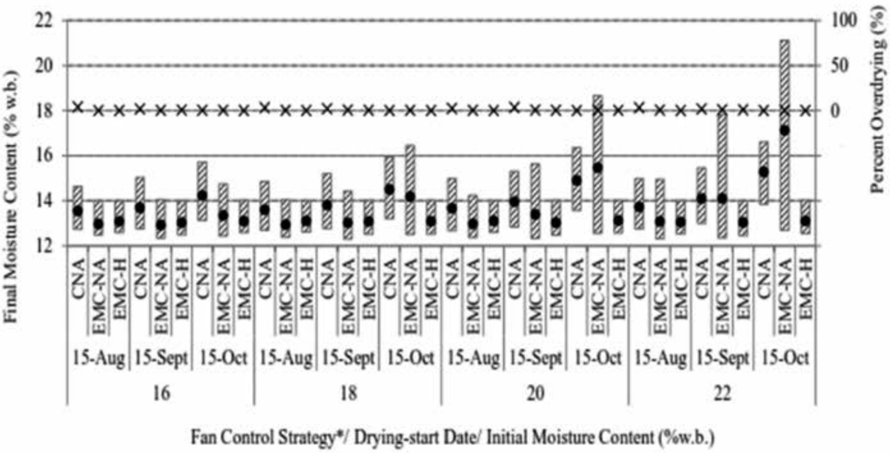
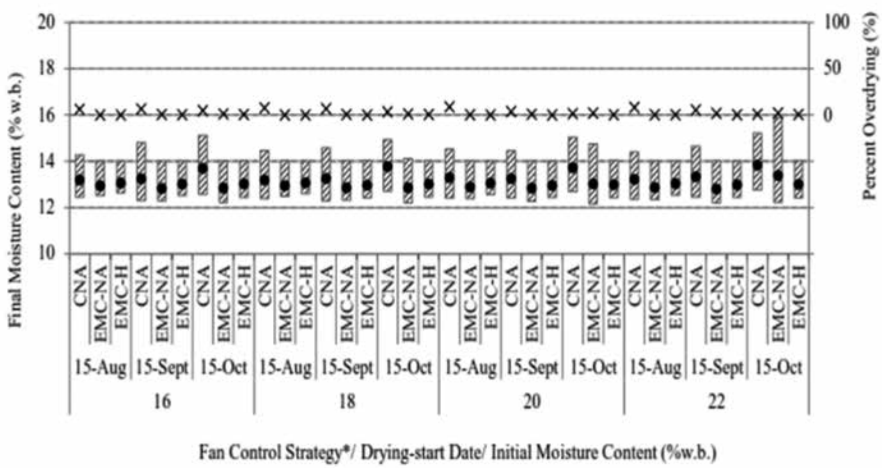


Fig. 2. Effect of initial moisture content (% wet basis, w.b.), fan control strategy (CNA, EMC-NA, and EMC-H), air flow rate, and drying-start date [(a) 15 August, (b) 15 September, and (c) 15 October] on rough rice maximum dry matter loss. CNA = continuous natural-air fan control strategy; EMC-NA = equilibrium moisture content controlled natural-air fan control strategy; EMC-H = equilibrium moisture content controlled air with supplemental heat fan control strategy. Each error bar was constructed using 1 standard deviation from the mean.



(a)



(b)

Fig. 3. Continued on next page.

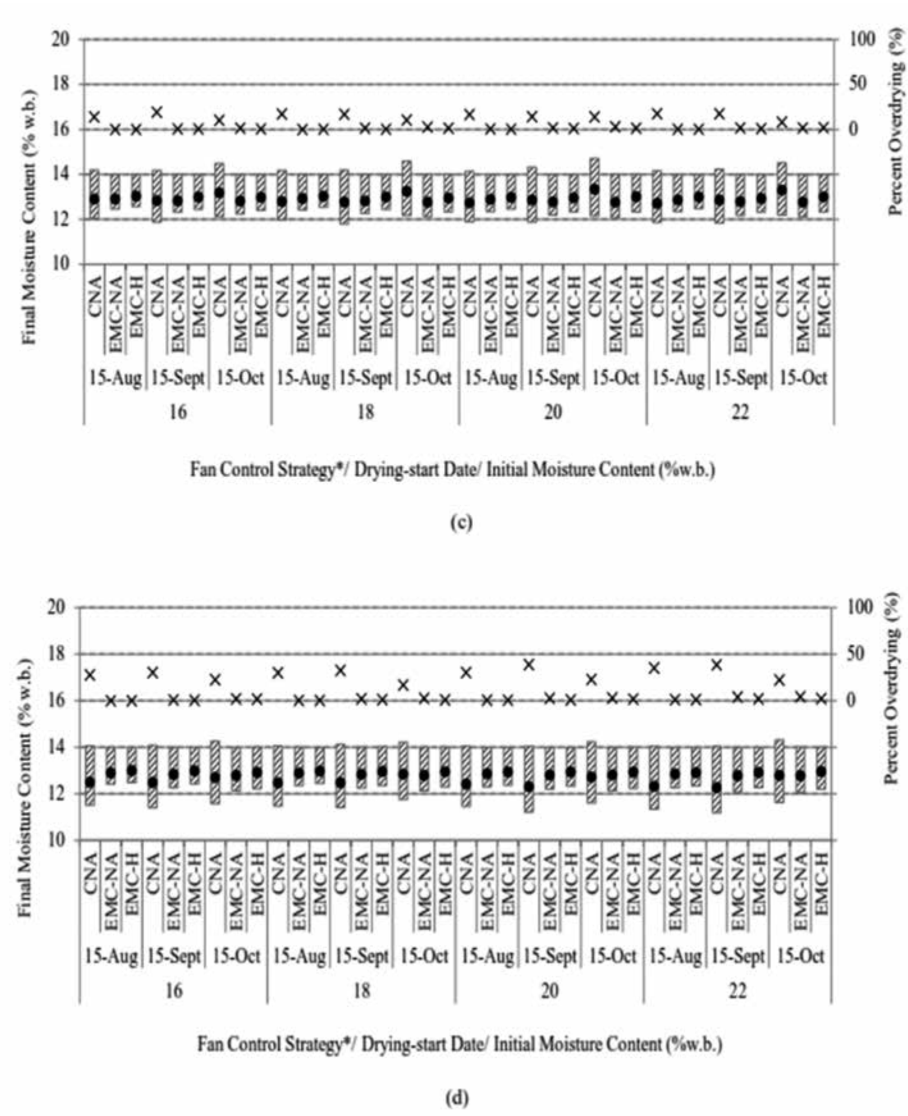


Fig. 3. Effects of initial moisture content (% wet basis, w.b.), fan control strategy, drying-start date, and airflow rate [(a) 0.69 m^3/min/ton (0.5 cfm/bu), (b) 1.39 m^3/min/ton (1 cfm/bu), (c) 2.08 m^3/min/ton (1.5 cfm/bu), and (d) 2.77 m^3/min/ton (2 cfm/bu)] on percent overdrying (right y-axis) and minimum, maximum, and average final moisture content of rough rice (left y-axis); The cross (×) and circular solid (●) marks represent the percent overdrying and the average final MC of the rice bed, respectively. The upper and lower limits of the solid box (▌) represent the average of the maximum and minimum final MCs attainable in the rice bed. CNA = continuous natural-air fan control strategy; EMC-NA = equilibrium moisture content controlled natural-air fan control strategy; EMC-H = equilibrium moisture content controlled air with supplemental heat fan control strategy.

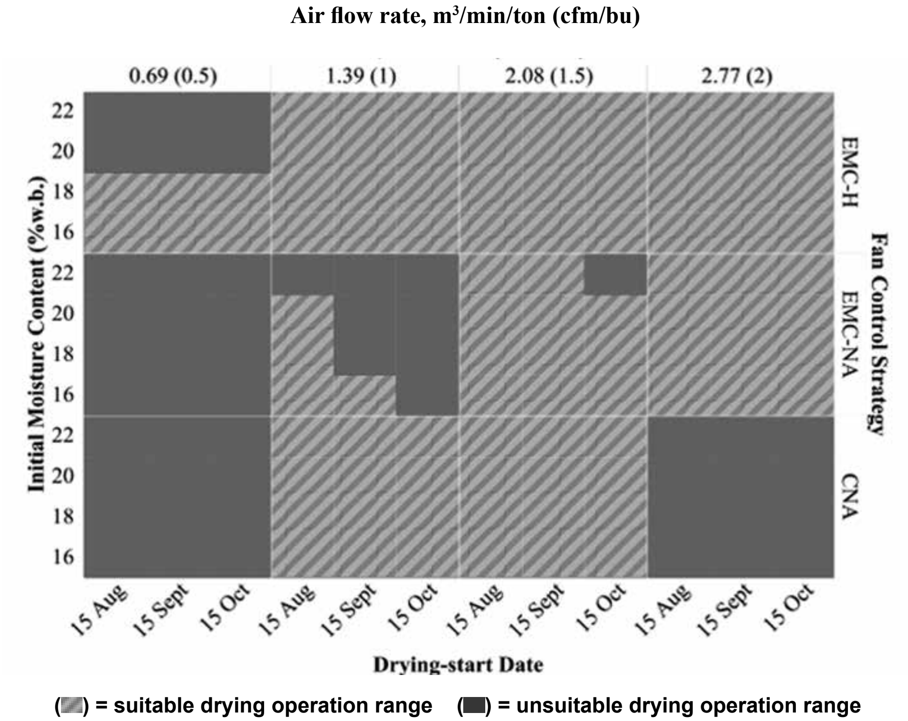


Fig. 4. Critical operation ranges for various drying strategies including initial moisture content (16%, 18%, 20%, and 22% wet basis, w.b.), fan control strategy (CNA, EMC-NA, and EMC-H), airflow rate [0.69 m^3/min/ton (0.5 cfm/bu), 1.39 m^3/min/ton (1 cfm/bu), 2.08 m^3/min/ton (1.5 cfm/bu), and 2.77 m^3/min/ton (2 cfm/bu)], and drying-start date (15 August, 15 September, and 15 October), that will limit rough rice drying within one month while maintaining DML and percent overdrying of equal or lower than 0.5% and 10%, respectively. CNA = continuous natural-air fan control strategy; EMC-NA = equilibrium moisture content controlled natural-air fan control strategy; EMC-H = equilibrium moisture content controlled air with supplemental heat fan control strategy.

Experimental Simulation of Cross-Flow Rice Dryers

S. Mukhopadhyay[1] *and T.J. Siebenmorgen*[1]

Abstract

Drying treatments were conducted in an experimentally simulated cross-flow drying column that allowed measurement of moisture content (MC) and head rice yield (HRY) at different locations within the column. Rice at 16.3% initial MC (IMC) was dried for 1 h using four drying air conditions and an airflow rate of 110 cfm/ft^2. Following drying, rice was tempered at the drying air temperature for that run for 4 h, then gently conditioned to 12% MC, milled and head rice separated. As expected, HRYs of the bulk of rice in the column decreased with increasing severity of the drying air condition, particularly when 135 °F/13% relative humidity (RH) and 147 °F/9% RH drying air were used. Moreover, at severe drying air conditions, HRYs of samples near the heated-air plenum were much less than the HRYs of rice into the column. Limited drying runs were also conducted using a 20.4%-IMC sublot; the bulk-column HRY for the 16.3%-IMC sub-lot was significantly greater compared to that for the 20.4%-IMC sublot, indicating that at a particular drying air condition, the MC reduction that can be achieved in a single pass without incurring HRY reduction is dependent on the IMC of the rice lot.

Introduction

Since the amount of rice that must be dried per unit time during the harvest season is increasing owing to greater production, harvesting, and transportation capabilities, there is a need to increase drying capacity. In some instances, on-farm, cross-flow dryers are being used to meet these needs. In these dryers, rough rice is typically dried in multiple passes, with periods of "tempering" between passes. Tempering allows intra-kernel moisture and material state gradients, which are typically created during drying, to subside (Cnossen and Siebenmorgen, 2000; Dong et al., 2009). This, in turn, improves the drying rate in subsequent drying passes (Nishiyama et al., 2006), thereby increasing energy efficiency (Hwang et al., 2009).

A study was conducted to quantify moisture content (MC) and milling yield patterns within an experimentally simulated, cross-flow drying column under a range of rice and drying air conditions. A portion of this study is reported herein.

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Procedures

Drying treatments were conducted in a specially designed apparatus that allowed measurement of MC and head rice yield (HRY) throughout a drying column. Head rice yield represents the mass of head rice (milled kernels that are at least three-fourths of the original kernel length) expressed as a percentage of the original, dried rough rice mass (USDA-FGIS, 2009).

A 700-lb bulk lot of rough rice (pure-line, long-grain cultivar Roy J) was combine-harvested at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center, Stuttgart, Ark., in the fall of 2015 at 23.2% MC. Unless otherwise specified, MC is reported on a wet basis. The lot was cleaned using a dockage tester (XT4, Carter-Day, Minneapolis, Minn.). Two sublots of 350 lb and 100 lb were gently conditioned to ~ 16.5% MC and 21% MC, respectively, using air at 79 °F/56% RH, then stored in sealed containers at 39 °F for 4 months. Immediately prior to drying treatments, the rice initial MCs (IMCs) of the 350-lb and 100-lb sublots were determined to be 16.3% and 20.4%, respectively, by drying duplicate, 15-g (0.03-lb) subsamples in a convection oven (1370FM, Sheldon Manufacturing Inc., Cornelius, Ore.) maintained at 266 °F for 24 h.

Drying treatments were conducted inside a 32-ft^3 chamber (Platinous Sterling Series, ESPEC, Hudsonville, Mich.) that was capable of producing drying air at desired temperature/relative humidity (T/RH) combinations. During operation, a centrifugal fan (4C108, Dayton Electric Manufacturing Co., Niles, Ill.) suctioned air at the desired T/RH from the chamber through a port located in the front door of the chamber, and then forced the air through a side-wall port in the chamber wall to a drying assembly (Fig. 1) inside the chamber. The assembly comprised a wooden box that served as a heated-air plenum (HAP), an acrylic glass drying column with a metallic screen base, and a set of ten, fiber-mesh, hand-woven cylindrical baskets (1.5-in. thick, 5-in. diameter). The fiber-mesh baskets enabled the drying column to be divided into discrete layers, thus permitting sampling at various distances from the HAP.

For the 16.3%-IMC sublot, the following drying air T/RH combinations were used: 104 °F/32% RH, 122 °F/18% RH, 140 °F/12% RH, 158 °F/8% RH with corresponding equilibrium MCs of 8.0%, 5.4%, 3.7%, and 2.2%, respectively (Modified Chung-Post equation, ASABE, 2012). A drying duration of 1 h and an airflow rate of 110 cfm/ft^2 were used. For the 20.4%-IMC sublot, a single drying treatment was conducted using 135 °F/13% RH drying air; the drying duration and airflow rate were the same as mentioned above. Duplicate drying runs were made for each treatment combination.

Approximately 6 lb of rough rice was removed from cold storage and equilibrated to room temperature (72 °F) for 24 h prior to each drying run. Each of the ten baskets was filled with 270 g (0.6 lb) of rough rice. Stacking the ten baskets in the acrylic glass cylinder resulted in a 15-in. thick rice column, which is typical of cross-flow dryer thicknesses used commercially. When the controlled-environment chamber stabilized at the T/RH setting for a drying run, the chamber door was opened for <1 min to position the rice column on the HAP. After a drying run, one of two tempering approaches were followed. In the first tempering approach, the contents of all ten baskets were immediately

(<1.5 min) mixed and a 1.1-lb sample was sealed in an airtight bag, which was then placed in a pre-heated oven at the drying air temperature for that drying run for 4 h. The sample was then spread into a thin layer on a perforated tray and immediately placed in a chamber maintained at 79 °F/56% RH to condition the rice to 12% MC for milling. In the second approach, each basket was placed in individual sealed airtight bags, which were then placed in the oven as described above. After the 4-h tempering duration, the contents of each basket were spread into thin-layers on individual perforated trays and similarly conditioned to 12% MC.

In addition to the samples taken for tempering, a 40-g (0.09-lb) sample was taken after mixing the contents of all the baskets, allowed to equilibrate in a sealed plastic bag at 72 °F for 48 h, and MC measured following the above oven-drying procedure to indicate the final average MC of the column. A 40-g sample was also taken from each basket for MC analysis to indicate the final MC as a function of distance from the HAP.

For each milling analysis, a 150-g (0.33-lb) rough rice sample was dehulled using a laboratory huller with a clearance of 0.048 cm (0.019 in.) between the rollers (THU-35A, Satake Engineering Co., Ltd., Tokyo, Japan). The brown rice was milled for 19 s (previously determined as the milling duration required to achieve 0.4% surface lipid content) using a laboratory mill (McGill No. 2, Rapsco, Brookshire, Texas) with a 1.5-kg (3.3 lb) mass placed on the lever arm 15 cm (5.9 in.) from the center of the milling chamber. A sizing device (61, Grain Machinery Manufacturing Co., Miami, Fla.) was used to separate head rice from brokens. Head rice yield was calculated as the mass of head rice, expressed as a percentage of the 150-g (0.33-lb) rough rice mass.

Control milling yields were produced by removing 5 lb of rough rice from the stored, bulk lot, equilibrating at 72 °F for 24 h, and conditioning to 12% MC using air at 79 °F/56% RH. Ten, 150-g samples were milled per the procedure described above and the yields averaged.

Results and Discussion

The actual drying air conditions at the HAP were 104 °F/26% RH, 122 °F/17% RH, 135 °F/13% RH, and 147 °F/9% RH, for the desired conditions of 104 °F/32% RH, 122 °F/18% RH, 140 °F/12% RH, and 158 °F/8% RH, respectively. Expectedly, final MCs of the bulk column decreased with increasing severity of the drying air condition (Fig. 2A). Head rice yields were similar at the 104 °F/26% RH and 122 °F/17% RH drying air conditions, of minimal reduction from the control, but decreased significantly when 135 °F/13% RH air was used, and then decreased drastically when 147 °F/9% RH air was used (Fig. 2B). These results indicate that ~16%-IMC rice can be dried to ~12.5% MC without incurring significant HRY reduction in a single pass (1-h duration) if drying air conditions are maintained in the range of 122 °F/17% RH to 135 °F/13% RH, provided sufficient tempering is allowed after drying.

The bulk trends (Fig. 2) were explained by the variation in MC and HRY throughout the individual baskets that constituted the 15-in. thick bulk column (Fig. 3). Non-uniformity of MCs within the drying column is evident from Fig. 3A; for all drying air conditions, final MCs increased with distance from the HAP. Moreover, as severity of the drying air condition increased, rice near the HAP was increasingly overdried, i.e., past the desired 12.5% MC level. For example, when using 135 °F/13% RH drying air, although the final MC of the bulk column was 12.6% (Fig. 2A), the rice in basket 1 (B1: nearest to the HAP) reached a final MC of 11.5% (Fig. 3A). Similarly, when using 147 °F/9% RH drying air, the final MC of the bulk column was 11.5%, but B1 reached a final MC of 10.1%; since the thickness of each basket was 1.5-in., it is likely that the rice kernels immediately adjacent to the HAP were severely overdried to MCs of 5% to 6% and would likely result in severe fissuring and consequent HRY reduction.

Figure 3B shows that HRYs across all baskets were similar when using 104 °F/26% RH and 122 °F/17% RH drying air, but when 135 °F/13% RH was used, B1 had a lesser HRY (56%) compared to the HRYs of B1 (58% to 59%) when milder drying air conditions were used. This trend was magnified with increasing severity of the drying air condition, with baskets near the HAP having drastically less HRYs for the 147 °F/9% RH drying air condition. These results confirmed that the rice layers near the HAP had significantly less HRYs compared to HRYs into the column, even if tempering was conducted after drying. Moreover, these severe HRY reductions in the rice layers near the HAP were responsible for causing a decrease in the HRY of the bulk column.

Figure 4 shows the MCs and HRYs of the individual baskets that constituted the 15-in. thick drying column for the 16.3%-IMC and the 20.4%-IMC rice, after 1 h of drying using 135 °F/13% RH drying air. The final bulk column MCs for the 16.3%-IMC and the 20.4%-IMC sublots were 12.6% and 15.2%, respectively, which represented a MC reduction of 3.7 percentage points (PPs) and 5.2 PPs, respectively. Interestingly, the bulk-column HRY for the 16.3%-IMC sublot (57.7%) was significantly greater than the bulk-column HRY for the 20.4%-IMC sublot (53.2%). This showed that the MC reduction that could be achieved in a single pass without incurring HRY reduction at a particular drying air condition, was dependent on the IMC of the rice lot, i.e., 16.3%-IMC rice could be dried to 12.6% MC in a single pass without incurring HRY reduction, but this was not possible if the rice was at 20.4% IMC.

Significance of Findings

This study showed that rice at ~16% IMC can be successfully dried to ~12.5% MC using single-pass drying for 1 h without incurring HRY reductions if drying air conditions are maintained in the range of 122 °F/17% RH to 135 °F/13% RH, provided sufficient tempering is allowed after drying. Additionally, the MC reduction that can be achieved in a single pass without incurring HRY reduction is dependent on the IMC of the rice lot. The HRY results obtained herein also confirm that under typical cross-flow dryer operating conditions, severe over-drying and resultant losses in HRY occur in the rice kernels adjacent to the HAP and that these HRY reductions near the HAP ultimately result in a lesser overall bulk-column HRY, thus negatively affecting the economic value of the rice.

Acknowledgments

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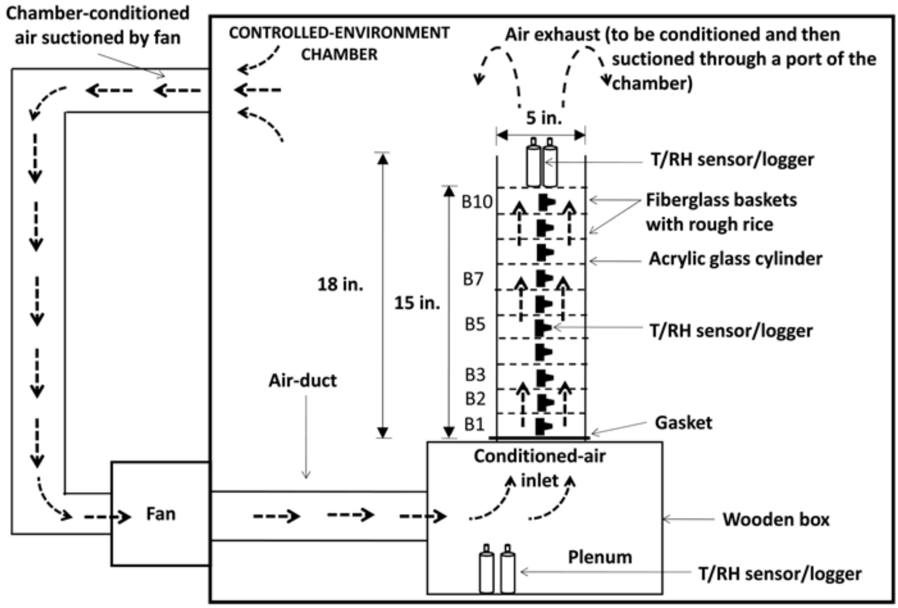

Fig. 1. Schematic diagram of the drying system. The drying assembly comprised a wooden box, an acrylic glass drying column with a metallic screen base, and a set of ten, fiber-mesh cylindrical baskets (B1-B10) filled with rough rice and temperature/relative humidity (T/RH) sensors/loggers, all positioned inside a controlled-environment chamber.

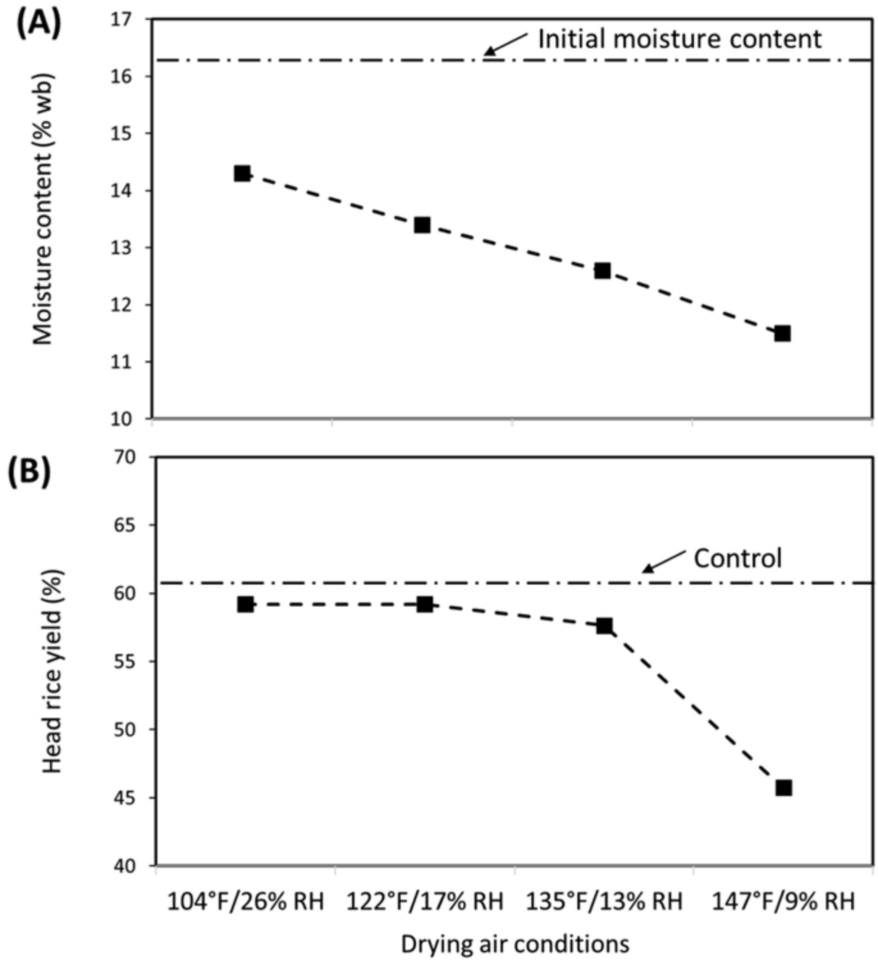

Fig. 2. (A) Moisture content (MC) and (B) head rice yield of the 15-inch thick bulk column after drying rough rice (cultivar Roy J) at 16.3% initial moisture content for 1 h using the indicated drying air conditions at an airflow rate of 110 cfm/ft^2. Contents of the entire column were mixed and held at the drying air temperature for 4 h, then conditioned at 79 °F/56% relative humidity (RH) to 12% MC and milled. Data points are the mean of two experimental treatment replications.

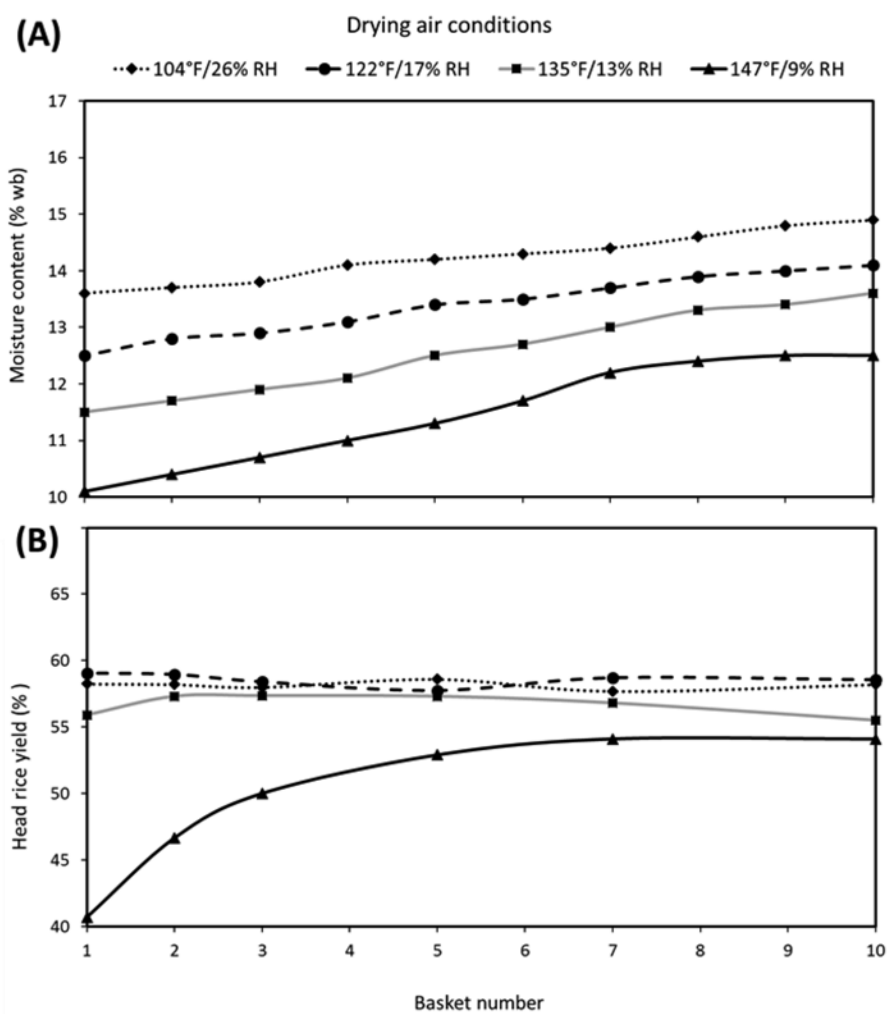

Fig. 3. (A) Moisture content (MC) and (B) head rice yield of the individual baskets that constituted the 15-inch thick rice column after drying rough rice (cultivar Roy J) at 16.3% initial MC for 1 h using the indicated drying air conditions at an airflow rate of 110 cfm/ft^2. Basket 1 was nearest to the heated-air plenum. Contents of each basket were placed in individual sealed bags and held at the drying air temperature for 4 h, then conditioned at 79 ºF/56% relative humidity (RH) to 12% MC and milled. Data points are the mean of two experimental treatment replications.

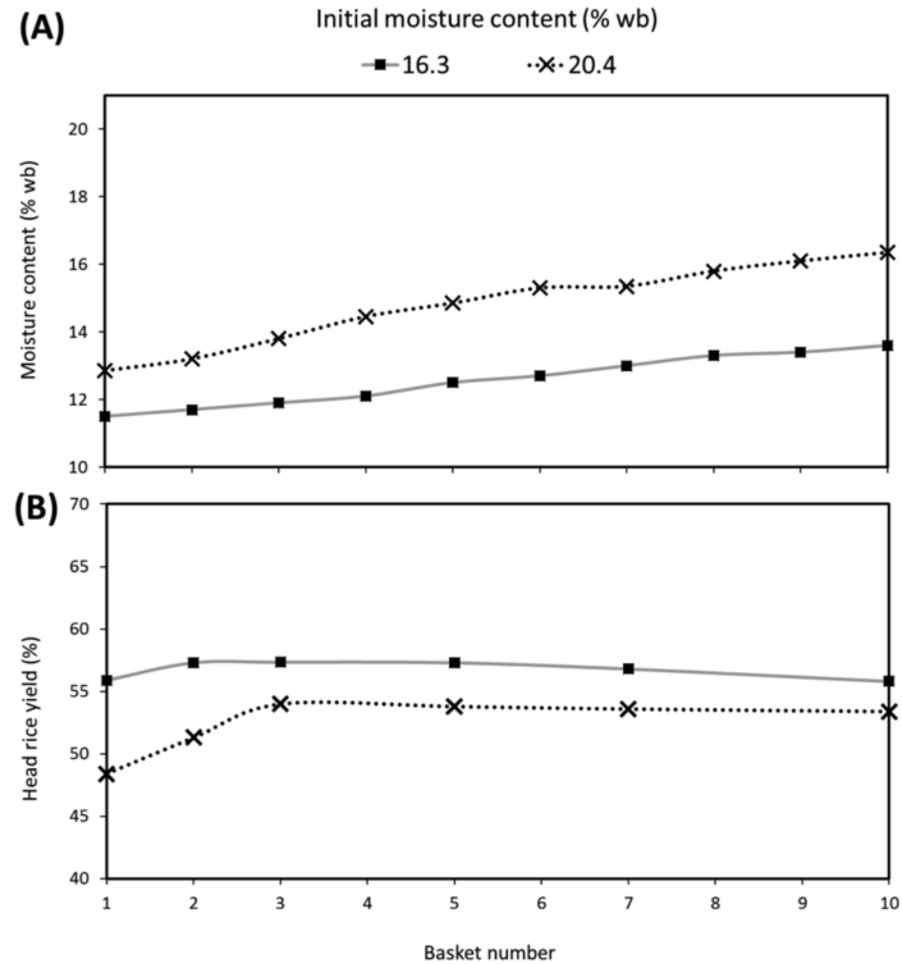

Fig. 4. (A) Moisture content (MC) and (B) head rice yield of the individual baskets that constituted the 15-inch thick rice column after drying rough rice (cultivar Roy J) at the indicated initial MCs using 135 °F/13% relative humidity (RH) at an airflow rate of 110 cfm/ft^2 for 1 h. Contents of each basket were placed in individual sealed bags and held at the drying air temperature for 4 h, then conditioned at 79 °F/56% RH to 12% MC and milled. Data points are the mean of two experimental treatment replications.

Rough Rice Drying Using A Pilot-Scale Infrared Heating System

A. Okeyo[1], S. Wilson[1], and G.G. Atungulu[1]

Abstract

Rough rice is normally harvested at moisture contents (MCs) higher than the safe storage MC and must therefore be dried immediately after harvest to lower the MC and maintain the grain quality. The objective for this study was to determine the effectiveness of scaled-up infrared (IR) drying of rough rice to improve drying rate and maintain the rice quality. An industrial type, pilot-scale dryer, designed to convey rough rice on a vibrating conveyor belt during IR heating was used. The heating zone of the equipment had catalytic IR emitters powered by natural gas. Freshly harvested, long-grain, pure-line rough rice (cv. Cheniere) at initial MC of 23.5% wet basis (w.b.) was heated with IR energy for 30, 50, 90 and 180 s followed by tempering at 140 °F (60 °C) for 4 h; all treatments were performed at loading rate of 2.29×10^{-3} lb/in.^{2} (1.61 kg m^{-2}), IR heating intensity of 7.89×10^{-3} lb/in.^{2} (5.55 kW m^{-2}), and at product-to-emitter-gap size of 17.71 in. (450 mm). The effects of the treatments on percentage points of moisture removal, head rice yield (HRY), rice color, and pasting characteristics were determined. One-pass IR heating and tempering treatments resulted in 3.3, 5.4, 9.4 and 11.4 percentage points of moisture removal after 30, 50, 90 and 180 s of IR heating, respectively. Two-pass IR heating treatments for durations lasting 30 and 50 s resulted in 7.3 and 9.5 percentage points of moisture removal, respectively. There was significant difference in the milled rice color indices, L* [(measures brightness from 100 (lightness) to 0 (darkness)], a* (measure of red-green color with positive a* values indicating redness and negative a* values indicating greenness), and b* (measure of yellow-blue color with positive b* values indicating yellowness and negative b* values indicating blueness) for treated and control samples. The samples treated for the longest duration of 180 s had higher degree of yellowness (b*). The head rice yield of control (63.6% HRY) samples was significantly different compared with samples that were treated with IR for 180 s (47.1 % HRY) in one-pass treatments, and 30 and 50 s (56.6% HRY and 58.4% HRY) in two-pass treatments. The peak and final viscosities of samples heated with IR for 180 s followed by tempering were significantly lower than those heated with IR for 30, 50 and 90 s. The setback viscosities of all the experimental samples were significantly greater than the controls. In conclusion, the study provided information crucial to scaling up radiant heating, especially for long-grain pure-line rice, which has not been studied before.

[1] Graduate Student, Graduate Student, and Assistant Professor, respectively, Department of Food Science, Fayetteville.

Introduction

In natural and convective heated air drying methods for rough rice, the air wet bulb temperature limits the heat flux to the rough rice and consequently the rice drying rate (Mujumdar and Devahastin, 2000; Pan et al., 2008). Since radiant heating with infrared (IR) is associated with high heat fluxes, it may be possible to use IR heating to achieve simultaneous microbial decontamination and increased rice drying rates without compromising the rice milling, sensory and functional quality indices (Afzal et al., 1999; Pan et al., 2008; Ratti and Mujumdar, 1995). In order to successfully implement the radiant drying process for industrial applications, there is need to test the effectiveness of the treatment at a scale and process that is comparable to what is expected in an industrial set up. The objectives for this study were to test the effectiveness of a newly built industrial type IR heating system to dry freshly harvested high moisture content (MC) rough rice. Specifically, the study evaluated the effect of IR heating in conjunction with tempering treatments to dry rice and maintain quality indices such as: (1) head rice yield (HRY); (2) pasting parameters in terms of final, peak, and setback viscosities; and (3) rice color.

Procedures

Rice Samples

Long-grain pure-line rice (cv. Cheniere) harvested in August 2014 at initial moisture content (IMC) of 23.5% wet basis (w.b.) was used in this study. The MCs of the samples were determined by using an AM 5200 Grain Moisture Tester (PERTEN Instruments, Hägersten, Sweden).

Infrared Drying and Tempering Experiments

Rice drying was conducted using a newly built, pilot-scale IR heating system equipped with catalytic IR emitters (Catalytic Industrial Group, Independence, Kan.). Rice samples were loaded on a moving belt as a single layer at a loading rate of 2.29 $\times 10^{-3}$ lb/in.^{2} (1.61 kg m^{-2}). The product-to-emitter-gap size was set at 450 mm. The samples were heated with IR for 30, 50, 90, or 180 s under IR heating intensity of 7.89 $\times 10^{-3}$ lb/in.^{2} (5.55 kW m^{-2}). Tempering of the heated rice was conducted immediately after IR heating. During tempering, the samples were placed in tightly sealed glass jars which were then placed in an environmental chamber (ESL 4CA Platinous Temperature and Humidity Chamber, Espec, Hudson, Mich.) set at 140 °F (60 °C); the rice was kept in the tempering environment for 4 h. The weights of rice samples were measured before and after IR heating and tempering. The weight loss during IR heating and the difference between IMC and the MC after treatment were used to calculate percentage point moisture removal. The experiments were conducted for single- (one) and two-pass IR heating and tempering treatments.

Milling Analysis

Triplicate, 0.33-lb (150-g) subsamples of rough rice, obtained from each sample dried to 12.5% MC, were dehulled using a laboratory huller (Satake Rice Machine, Satake Engineering Co., Ltd., Tokyo, Japan), milled for 30 s using a laboratory mill (McGill #2 Rice Mill, RAPSCO, Brookshire, Texas) and aspirated for 30 s using a seed blower (South Dakota Seed Blower, Seedboro, Chicago, Ill.). Head rice was considered as kernels that retained at least three-fourths of the original kernel length after milling (Siebenmorgen, 2014). Head rice yield was calculated as the mass proportion of rough rice that remained as head rice after complete milling.

Pasting Viscosity Profiles

Rapid Visco Analyzer (RVA)-Super 4 (Newport Scientific Pty. Ltd., Warriewood, NSW, Australia) was used to determine the peak and final viscosity of the rice flour. The RVA was set up on a 12.5 min routine (1.5 min at 122 °F (50 °C), heating to 203 °F (95 °C) at 54 °F (12 °C)/min, 2.5 min at 203 °F (95 °C), cooling to 122 °F (50 °C) at 54 °F (12 °C)/ min, and held for 1 min at 122 °F (50 °C) according to AACC Methods (1996). Peak and final viscosities were recorded in centipoises (1 RVA unit = 10 cP).

Statistical Analyses

Analysis of variance, Student's *t*-test (least significant difference test), and the Tukey's 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.

Results and Discussion

Moisture Removal Under Different Infrared Drying Durations

The percentage points of moisture removed from rice samples with IMC 23.5% are shown in Fig 1. The percentage points of moisture removed after one-pass IR heating and tempering treatments were 3.3, 5.4, 9.4 and 11.4 for samples heated with IR for 30, 50, 90 and 180 s, respectively. When the rice was subjected to two-pass treatments of 30 and 50 s IR heating and tempering, the percentage points of moisture removed were 7.3 and 9.5, respectively. There was no significant difference between the percentage point of moisture removed from rice dried in one-pass IR treatment for 90 s and two-pass treatment for 50 s. The rice moisture removal upon IR heating increased with increased heating duration in both one- and two-pass treatments. The increased moisture removal resulted from increased energy supply to the rice during prolonged heating durations (Pan et al., 2011). It is possible that conveyor belt vibration allowed uniform exposure of rice to IR heat thereby improving the drying rate of rice in the industrial type IR drying system.

Head Rice Yield

The HRYs of samples dried using IR heating for 30, 50, 90 and 180 s per pass and tempered at 140 °F (60 °C) for 4 h are shown in Fig. 2. The HRYs observed in samples dried using IR heating for 30, 50 and 90 s in a one-pass treatment followed by tempering (61.8%, 60.4% and 60.5% respectively), were significantly different ($P < 0.05$) from the HRY of control samples (63.9% HRY). The result showed that the two-pass treatments significantly ($P < 0.05$) lowered the sample HRY compared to one-pass treatment for heating durations of 30 and 50 s. For one-pass treatment alone, the reduction of HRY was significant ($P < 0.05$) when samples were exposed to IR heating for durations exceeding 180 s (47.1%). The significant HRY reduction may have been caused by the intra-kernel stresses resulting from the material state differences between the surface and the core (Ondier et al., 2012). Overall, better milling quality ($P < 0.05$) was observed in samples treated for shorter durations than for samples treated for longer durations.

Color

Rice whiteness, expressed as L* values, and yellowness expressed as b* values are shown in Fig. 3. No significant difference was observed between the rice whiteness of the control and experimental samples treated for 180 s in one-pass ($P > 0.05$), while all other treatments slightly decreased rice whiteness ($P < 0.05$). There was also no significant difference ($P > 0.05$) between the rice yellowness of the control and all the samples treated in a single pass, for all the drying duration except for samples treated for the longest duration (180 s). Increased rice yellowness was observed in samples treated with two passes for the 30 s per pass. There is a possibility that the high-energy flux associated with IR heating leading to faster MC reduction could inactivate enzymes responsible for rice yellowing or browning reactions (Maillard reaction).

Pasting Property

Peak and final viscosities of samples heated with IR for 180 s followed by tempering were significantly affected compared to those heated with IR for 30, 50 and 90 s (Fig. 4). It was observed that using one- or two-pass treatment did not affect the peak and final viscosities of rice. The highest final viscosities were observed in samples dried with IR for 30 s in a two-pass treatment (2090 Cp). The highest peak viscosity was observed in samples dried with IR in a one-pass treatment of 50 s (1418 Cp), but this was not significantly different ($P > 0.05$) from all other experimental samples. The setback viscosity of all the experimental samples were significantly greater ($P < 0.05$) than the controls. Longer IR heating durations were associated with higher setback viscosities. The changes in pasting viscosity profiles in the experimental sample results may be attributed to chemical and structural changes occurring within the rice kernel when exposed to IR heating (Table 1). Starch generally has the greatest influence on the pasting viscosity profile of rice flour (Patindol et al., 2003). Since the denaturation temperature of rice proteins which include albumin, glutelin and globulin ranges between

158 °F (70 °C) and 176 °F (80 °C) (Ju et al., 2001), it is possible that the IR heating at intensity of 7.89×10^{-3} lb/in.^{2} (5.55 kW m^{-2}) disrupted the disulfide bonds and caused the starch granule to swell to a larger size (Table 1). The increase in pasting viscosity profile of the treated rice samples may have been due to release of amylose and low molecular weight amylopectin chains of starch granules (Dang and Copeland, 2004), which promotes the formation of polymer complexes that significantly contributed to the increased viscosity of the IR-treated samples.

Significance of Findings

These findings suggest that scaled-up radiant IR treatment of rice followed by tempering could be optimized to remove significant amounts of moisture from the rice with few passes, maintain desirable HRY and other quality indices, such as rice color and pasting characteristics.

Acknowledgments

The authors greatly appreciate the University of Arkansas System Division of Agriculture for partially funding this research, the Grain Processing Research group and the Rice Processing Program (of the University of Arkansas System Division of Agriculture) for collaboration, technical support, and sample preparation and collection.

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Table 1. Surface temperature of rice at initial moisture content of 23.5% wet basis before and after infrared heating for 30, 50, 90 and 180 s. Each value is an average of three replicate measurements.

Infrared heating duration	Surface temperature in	Surface temperature out
(seconds)	--------------------------------(ºF)	---------------------------------
30	75.7 (24.3 °C)	140.9 (60.5 °C)
50	73.2 (22.9 °C)	147.7 (64.3 °C)
90	72.7 (22.6 °C)	163.0 (72.8 °C)
180	76.8 (24.9 °C)	242.2 (116.8 °C)

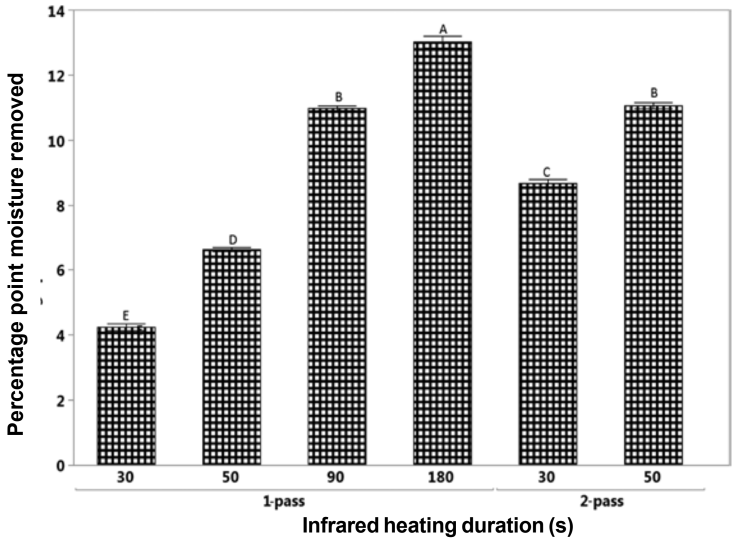

Fig. 1. Percentage point moisture removed after one-pass and two-pass infrared heating and tempering of rice for different heating durations. Each value is an average of three replicate measurements. Levels without the same letter are significantly different (*P* < 0.05).

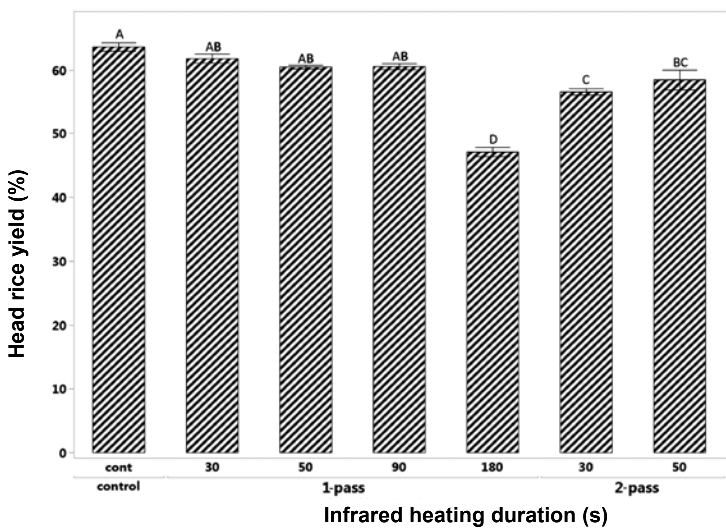

Fig. 2. Head rice yield after one-pass and two-pass infrared heating and tempering of rice for different drying durations. Control (cont) samples were dried at 79 °F (26 °C) and 65% relative humidity to 12.5% moisture content wet basis. Each value is an average of three replicate measurements. Levels without the same letter are significantly different (*P* < 0.05).

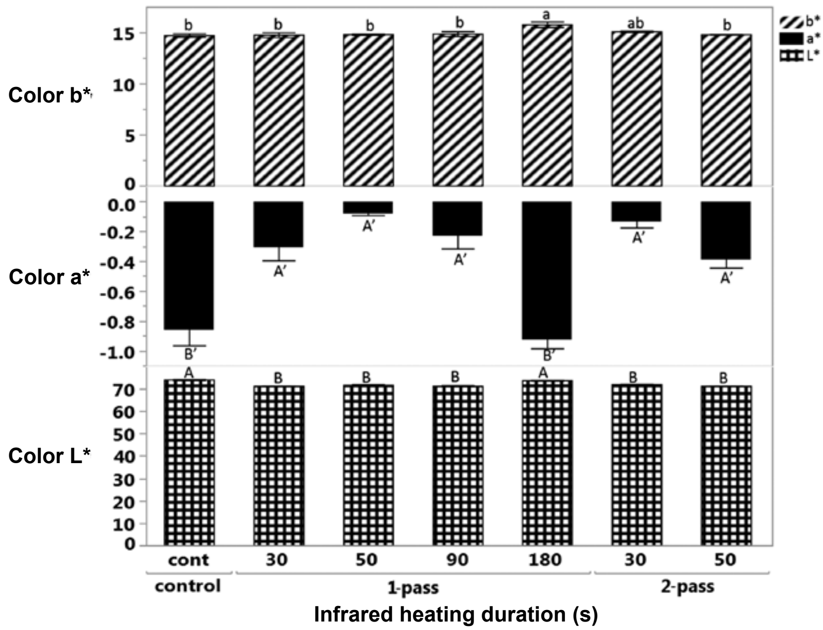

Fig. 3. Color parameters L* (measures brightness from 100 (lightness) to 0 (darkness)), a* (measure of red-green color with positive a* values indicating redness and negative a* values indicating greenness), and b* (measure of yellow-blue color with positive b* values indicating yellowness and negative b* values indicating blueness) of rice samples after one-pass and two-pass infrared heating and tempering for different drying durations. Control (cont) samples were dried at 79 °F (26 °C) and 65% relative humidity to 12.5% moisture content wet basis. Each value is an average of three replicate measurements. Values without the same letter are significantly different ($P < 0.05$).

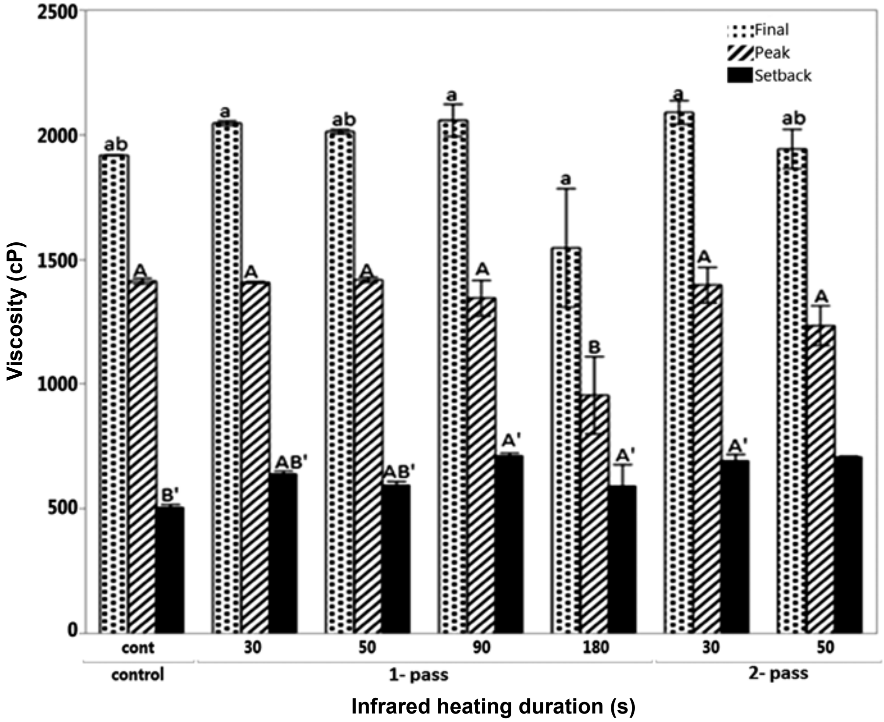

Fig. 4. Peak, final and setback viscosities of rice after one-pass and two-pass infrared heating and tempering for different drying durations. Control samples were dried at 79 °F (26 °) and 65% relative humidity to 12.5% moisture content wet basis. Each value is an average of three replicate measurements. Means with the same type of letters are not significantly different (*P* < 0.05).

Assessment of One-Pass Microwave Drying Followed by Tempering and Cooling Treatments on Milling Quality of Rice

D.L. Smith[1], S.A. Wilson[1], and G.G. Atungulu[1]

Abstract

The volumetric heating phenomenon of microwaves has the potential to dry rough rice rapidly with reduced inter-kernel rice temperature and moisture content (MC) gradients; this may minimize rice fissuring and maintain milled rice quality. The objective for this study was to determine the feasibility of using an industrial-type microwave heating system to achieve one-pass rice drying with minimum implications on rice milling quality, especially the head rice yield (HRY). Freshly harvested, medium-grain rough rice samples (cv. Jupiter) at initial moisture content (IMC) of 23% to 24% (wet basis, w.b.) were heated using an industrial microwave system with a frequency of 915 MHz. The system was set to transmit energy to rice at power levels of 2, 5, 10 and 15 kW for durations of 1, 2, 3, and 4 min. The effects of natural-air and forced-air cooling and tempering of the rice after microwave treatments on moisture removal and HRY reduction were determined. Results showed that microwave treatments at power levels of 5 kW and 15 kW for 4 and 1 min, respectively, showed much promise in decreasing the rice MC to 13.0% w.b. for a rice bed thickness at 0.03 m. Supplying microwave energy of up to 600 kJ/kg-grain followed by 4 h of tempering at 60 °C caused drying of the rice to final MCs of 14% to 16%, and the resulting HRY was not significantly different from that of rice dried with natural air at 25 °C and relative humidity of 65%. The marginal reduction in HRY, especially that resulting from microwave heating followed by tempering treatment, provided a strong justification to optimize the treatments to achieve commercially viable rough rice drying throughput.

Introduction

Temperature and moisture content (MC) gradients which develop during convective heated- and natural-air drying of rice may cause differential stresses within the rice leading to kernel fissuring and overall weakening of mechanical properties, which negatively impact the rice milling yield. The rice milling yield, in large part, is quanti-

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fied by the head rice yield (HRY); the HRY comprises milled rice kernels that are at least three-fourths of the original kernel length and represents the mass percentage of a rough rice lot that remains as head rice after milling (Cnossen and Siebenmorgen, 2000). Preventing HRY reduction during drying is very critical and bears significant economic importance to the rice industry. This study hypothesized that the volumetric heating phenomenon that is accorded by microwave heating may reduce stresses caused by temperature and MC gradients within the rice kernel and potentially improve the rice milling yield. In addition, the high and rapid heat flux accorded by microwave heating may achieve one-pass drying of high-MC rice with minimized quality reduction.

Although microwave heating is expected to be volumetric, introducing tempering of rice, at temperatures above ambient and close to the rice surface temperature after microwave heating, may aid stepwise cooling and moisture redistribution within kernels, which ultimately may improve the quality of dried rice. Sudden exposure of rice to ambient conditions may result in inter-kernel temperature and moisture content gradients. Such gradients cause stresses within the rice kernel leading to fissuring and ultimately kernel cracking, which reduces HRYs.

In order to successfully implement microwave technology for rice drying, there is need to optimize the process such that rice milling yield is improved and the rice sensory, nutritional, and functional quality indices are maintained. The objective for this research was to determine the feasibility of using an industrial-type microwave heating system to achieve one-pass rice drying with minimum implications on the rice quality. The specific objectives for this study were the following:

1. Investigate the effects of microwave heating power and treatment duration on rice moisture removal.
2. Study the effectiveness of microwave heating of rice to achieve one-pass drying without adversely affecting the rice milling yield.
3. Study the implications of introducing tempering steps after microwave heating on rice milling yield.
4. Investigate the effect of natural- and forced-air cooling of the rice after microwave treatment on the rice milling yield.

Procedures

The study used medium-grain rice (cv. Jupiter) which was grown in the 2014 rice crop season at Cash, Ark. The samples were freshly harvested at initial MC of 23% to 24% w.b., immediately cleaned using dockage equipment (MCi Kicker Dockage Tester, Mid-Continent Industries Inc., Newton, Kan.), transferred into tubs, sealed and stored in a laboratory cold room set at 4 °C. The MCs of the samples reported in this study were determined using an AM 5200 Grain Moisture Tester (PERTEN Instruments, Hägersten, Sweden), which was calibrated according to the American Society of Biological Engineers (ASABE) standard (Jindal and Siebenmorgen, 1987). All reported MCs are on wet basis (w.b).

Microwave Equipment and Treatments

The implications of three different microwave treatment methods were studied; the treatment methods included 1) microwave heating followed by natural-air cooling, 2) microwave heating followed by tempering and natural-air cooling, and 3) microwave heating followed by forced-air cooling. For all the treatments, a sample of 2000 g rice was massed out and placed into microwave safe trays [0.31 m × 0.39 m (12 in. × 15.5 in.)]. The sample bed thickness was 0.03 m. The outsides of the trays were made of polypropylene with a Teflon-coated fiberglass mesh at the bottom to hold the samples. The tray with rice sample was set in the oven, on the belt and treated at various power levels and durations (Table 1). The surface temperature of rice after microwave heating was measured using an infrared thermometer (Fluke Corporation, Everett, Wash.).

In the case of microwave heating followed by tempering and natural-air cooling treatments, the samples were transferred immediately after heating to glass jars and sealed airtight. A HOBO sensor (Onset Computer Corporation, Bourne, Mass.) was placed in the jars to determine the changes in temperature and relative humidity inside the jars. The jars were placed in an environmental chamber (Platinous chamber, ESPEC North America, Inc. Hudsonville, Mich.) set at a temperature of 60 °C and relative humidity of 65%. The rice was tempered for 4 h.

In the case of microwave heating followed by forced-air cooling, the samples were not tempered, but spread uniformly on a perforated tray after the microwave treatment, and transferred to an environmental chamber (Platinous chamber, ESPEC North America, Inc. Hudsonville, Mich.) set at a temperature of 25 °C and relative humidity of 65%. At the bottom of the tray, a fan was installed to force air through the rice during cooling. The apparatus to allow the forced-air cooling consisted of a fan (DAYTON blower, Dayton Electric Mfg., Niles, Ill.) with airflow rate of 64.2 m^3h^{-1} through the rice to cool it to 25 °C.

After treatments and each respective cooling strategy, the samples were transferred immediately to an Equilibrium Moisture Content (EMC) chamber (Platinous chamber, ESPEC North America, Inc. Hudsonville, Mich.) set at a temperature of 25 °C and relative humidity of 65% and allowed to cool naturally to room temperature conditions. After cooling, the weight of the samples was determined and the percentage point of moisture removed was calculated.

After the MC of the rough rice was determined, the treated samples were left in the environmental chamber to dry to a MC of 12.5%, which is typically used to perform milling quality tests. Control samples constituted samples that were not treated with microwave but dried to a MC of 12.5% in an EMC chamber (Platinous chamber, ESPEC North America, Inc. Hudsonville, Mich.) set at a temperature of 25 °C and relative humidity of 65%.

Rice Milling

Triplicate, 150-g subsamples of rough rice, obtained from each sample dried to 12.5% MC, were dehulled using a laboratory huller (Satake Rice Machine, Satake

Engineering Co., Ltd., Tokyo, Japan), milled for 30 s using a laboratory mill (McGill #2 Rice Mill, RAPSCO, Brookshire, Texas) and aspirated for 30 s using a seed blower (South Dakota Seed Blower, Seedboro, Chicago, Ill.). Head rice was then separated from broken kernels using a double-tray sizing machine (Grainman Machinery Manufacturing Corp., Miami, Fla.). Head rice yield was calculated as the mass proportion of whole rice kernels that remains after milling.

Statistical Analyses

Analysis of variance, Student's *t* test (least significant difference test), and the Tukey's 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.

Results and Discussion

The effect of microwave heating duration and power level on rice MC for different drying strategies is shown in Fig. 1. The MCs are shown on the vertical *y*-axis for the three employed drying strategies. For commercial purposes, the targeted safe storage MC of rough rice should be 13%. Based on the results of this study, multiple passes of microwave treatment would be necessary to dry the rice to safe storage MC when low power levels are used for short heating durations. As shown in Fig. 2, regardless of the drying strategy employed in the study, it was found that microwave treatments that supplied specific energy of 600 kJ/kg-grain were effective in reducing the MC of rough rice to near storage moisture content in one-pass drying.

The HRY is often the most important quality parameter to millers since the HRY is generally linked to payment received for rice delivered at milling facilities. Figure 3 shows the HRY obtained following microwave treatment of rice with different power levels and treatment durations. The HRY are shown on the *y*-axis for the three employed drying strategies. The study revealed that microwave heating followed by tempering and natural cooling maintained HRYs similar to the control samples with treatments using microwave-specific energy of up to 600 kJ/kg-grain. However, as shown in Fig. 4, the other two studied strategies resulted in decline of HRYs as the treatment-specific energy exceeded 300 kJ/kg-grain.

Significance of Findings

Based on the findings of this feasibility study, there is potential to scale up microwave treatment of rice to achieve one-pass drying treatment. Supplying microwave energy of up to 600 kJ/kg-grain (medium-grain rice at IMC of 23% to 24% MC), and incorporating an additional 4 h tempering step at 60 °C dried the rice grain to final MC of 14% to 16% with HRY not significantly different from gently dried (natural air at 25 °C and relative humidity of 65%) control samples. The MC reduction and the HRY resulting from microwave heating followed by natural-air cooling and microwave heating followed by forced-air cooling were inferior compared to the strategy which incorporated tempering.

Acknowledgments

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Table 1. Drying methods, microwave power levels and heating durations used in the rice drying experiments. The power levels 2, 5, 10 and 15 kW correspond to 6.8×10^3, 17.1×10^3, 34.1×10^3, and 51.2×10^3 Btu/h, respectively.

	Microwave heating followed by																				
Method	**Natural-air cooling**							**Tempering**							**Forced-air cooling**						
Power (kW)	15	10	5				2	15	10	5				2	15	10	5				2
Duration (min)	1	1	1	2	3	4	4	1	1	1	2	3	4	4	1	1	1	2	3	4	4

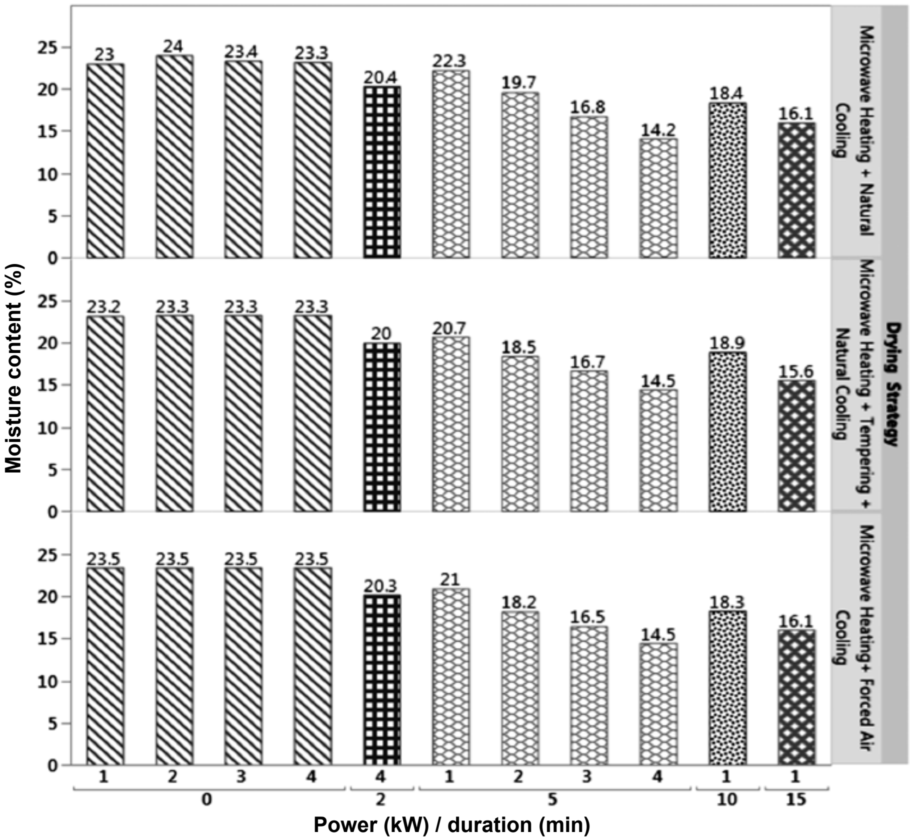

Fig. 1. The effect of microwave heating power level (0 to 15 kW) and duration (1 to 4 min) on moisture removal (% wet basis) for different rice-drying strategies.

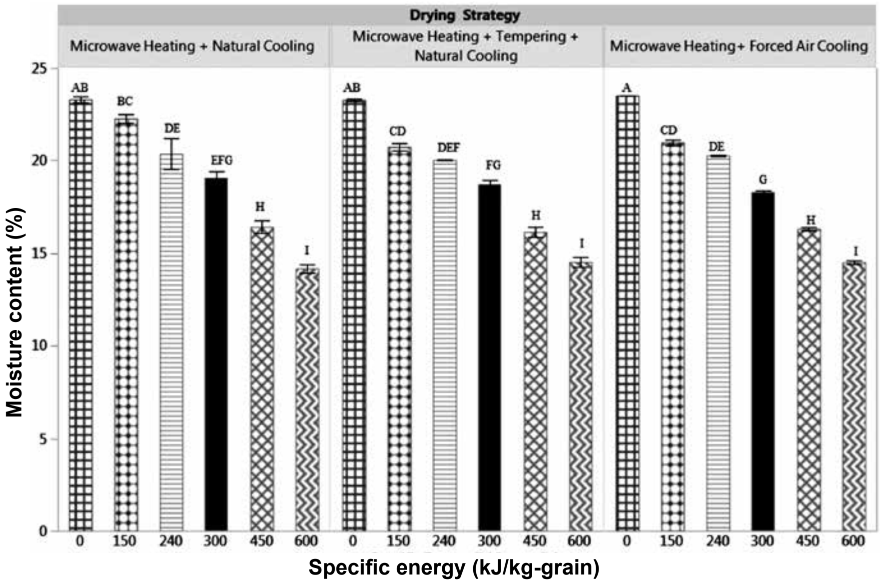

Fig. 2. The effect of specific energy supplied by microwave heating on moisture content (% wet basis) of the dried rice for different drying methods.

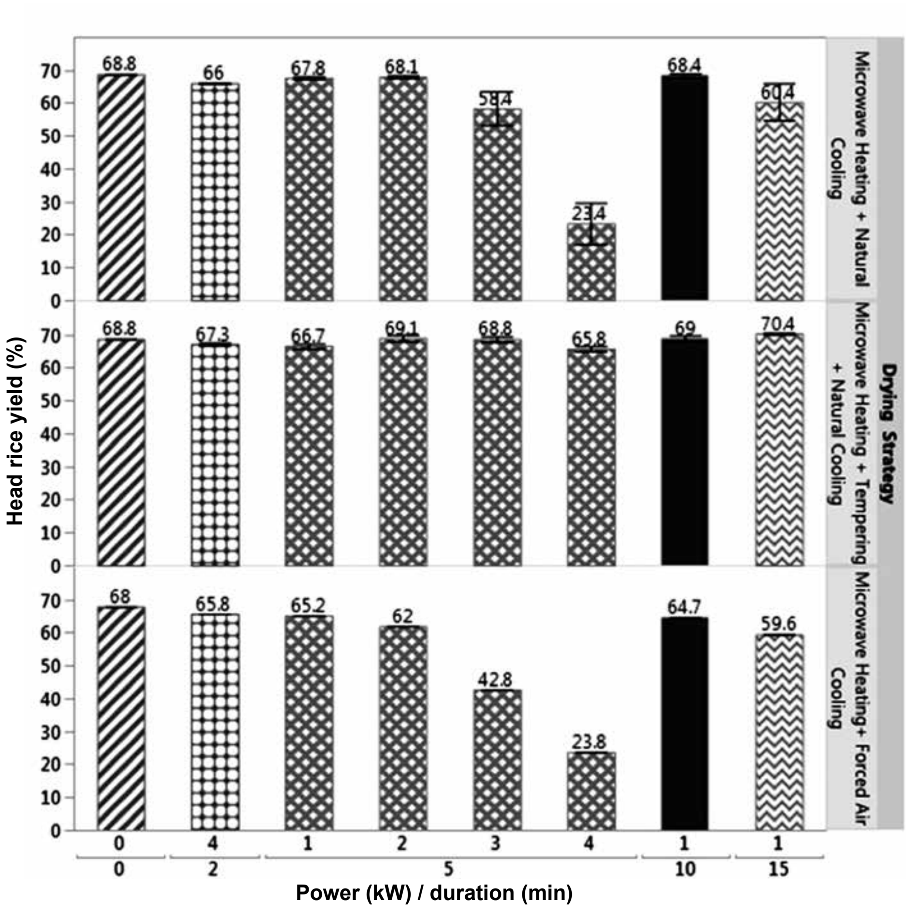

Fig. 3. The effect of microwave treatment power and heating duration on the head rice yield (HRY).

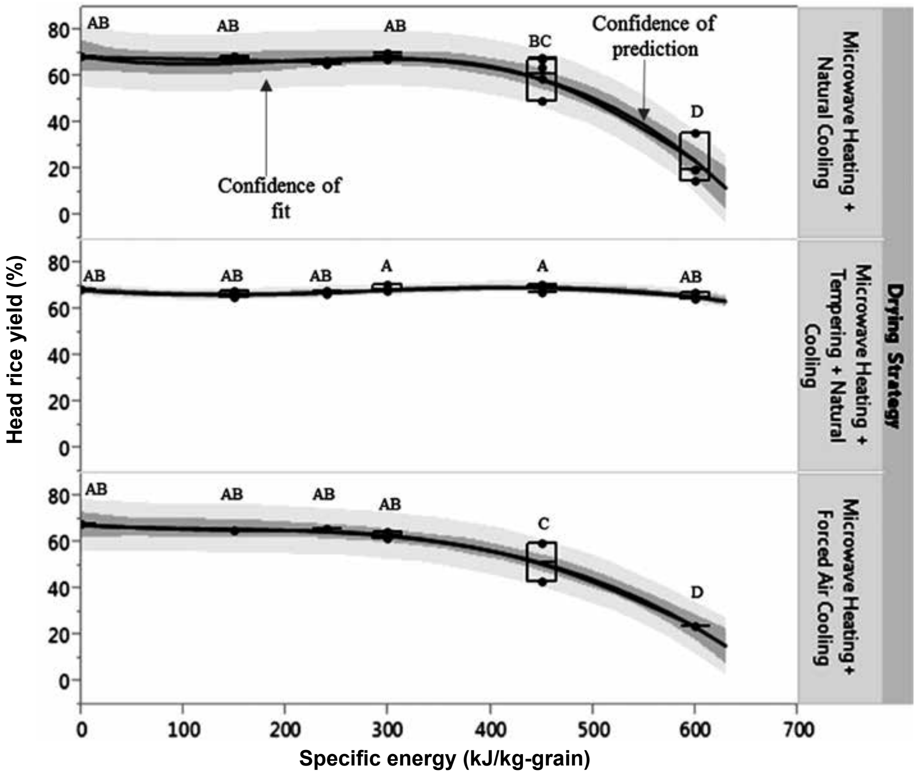

Fig. 4. The effect of specific energy supplied during microwave treatment on head rice yield.

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 the University of Arkansas System Division of Agriculture's Cooperative Extension Service 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 was to develop an interactive computational program that will enable stakeholders of the Arkansas rice industry to evaluate production methods for comparative costs and returns.

Procedures

Methods employed for developing crop enterprise budgets include input prices that are estimated directly from information available from suppliers and other sources, as well as costs estimated from engineering formulas developed by the American Society of Agricultural and Biological Engineers. Input costs for fertilizers and chemicals are estimated by applying prices to typical input rates. Input prices, custom hire rates, and fees are estimated with information from industry contacts. Methods of estimating these operating expenses presented in crop enterprise budgets are identical to producers obtaining cost information for their specific farms.

Ownership costs and repair expenses for machinery are estimated by applying engineering formulas to representative prices of new equipment (Givan, 1991; Lazarus

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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, 2016). 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 2016. Representative prices for machinery and equipment are based on contacts with Arkansas dealers, industry list prices, and reference sources (Deere and Company, 2016; MSU, 2016). Revenue in crop enterprise budgets is the product of expected yields from following the University of Arkansas System Division of Agriculture Cooperative Extension Service practices under optimal growing conditions and projected commodity prices.

Results and Discussion

The University of Arkansas System Division of Agriculture's Cooperative Extension Service 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. 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 $233.34/acre. The budget program includes similar capabilities for Clearfield, hybrid, Clearfield hybrid, and 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 $4.75/bu, input costs could be insured at selected coverage levels greater than 42%. Production expenses represent what are commonly termed as "out-of-pocket costs," and could be insured at coverage levels greater than 49%. Total specified expenses could be insured at coverage levels of 81%.

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.

Acknowledgments

This research is made possible by funding from the Arkansas Rice Research and Promotion Board and the University of Arkansas System Division of Agriculture.

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Table 1. Summary of revenue and expenses, conventional rice, per acre and per 1000 acres, 2017.

Revenue	Acre	Farm	Farm	Per acre
Acres	1	1,000	Farm	
Yield (bu)	180.0	180,000	APH[a] Yield	162.0
Price ($/bu)	4.75	4.75	Projected Price	4.75
Grower share	100%	100%		
Total crop revenue	855.00	855,000	Revenue	769.50

Expense	$/Acre	$/bu	$/Farm	Percent of revenue
				(%)
Seed	30.96	0.17	30,960	4
Fertilizers and nutrients	88.70	0.49	88,699	12
Chemicals	86.58	0.48	86,577	11
Custom applications	44.10	0.25	44,100	6
Diesel fuel, field activities	13.93	0.08	13,927	2
Irrigation energy costs	62.01	0.34	62,009	8
Other inputs	0.70	0.00	700	0
Input costs	326.97	1.82	326,972	42
Fees	8.00	0.04	8,000	1
Crop insurance	6.00	0.03	6,000	1
Repairs and maintenance, includes employee labor	25.57	0.14	25,574	3
Labor, field activities	12.51	0.07	12,514	2
Production expenses	379.06	2.11	379,060	49
Interest	7.96	0.04	7,960	1
Post-harvest expenses	119.43	0.66	119,430	16
Custom harvest	0.00	0.00	0	0
Total operating expenses	506.45	2.81	506,450	
Returns to operating expenses	348.55	1.94	348,550	
Cash land rent	0.00	0.00	0	0
Capital recovery and fixed costs	115.21	0.64	115,208	15
Total specified expenses	621.66	3.45	621,659	
Returns to specified expenses	233.34	1.30	233,341	
Operating expenses/bu	2.81	2.81		
Total specified expenses/bu	3.45	3.45		

[a] APH = actual production history.

Assessment of United States–Mexico Trade Relations and Their Impact on the U.S. Rice Sector

A. Durand-Morat[1] *and E.J. Wailes*[1]

Abstract

Exports account for 46% of the total U.S. rice market for the past five marketing years. Much of U.S. rice exports benefit from regional and bilateral trade agreements including the North American Free Trade Agreement (NAFTA), Central American Free Trade Agreement-Dominican Republic (CAFTA-DR), and the U.S.-Colombia Free Trade Agreement. Among these agreements, the NAFTA agreement is extremely important as the U.S. benefits from zero tariff duties on our shipments of rough and milled long-grain rice to Mexico. Mexico is by far the largest and most important export destination for U.S. long-grain rice. This study estimates the economic impact of this market for the U.S. rice sector.

Introduction

Shortly after the inauguration of President Trump, the White House suggested consideration of imposing a 20% tax on imports from Mexico to pay for the border wall to stem illegal immigration. Mexico is the third largest overall trade partner with the U.S. after Canada and China (USCB, 2017), and the largest source of agricultural imports (USDA-ERS, 2017). Imposing an import tariff on Mexican goods raises prices of Mexican goods for U.S. consumers but also imposes losses on Mexican industries who export to the U.S. The most likely response by Mexico to this economic threat is to respond with equivalent or even harsher trade sanctions.

Mexico is the largest market for U.S. long-grain rice, accounting for around 25% of U.S. long-grain rice exports in the last several years (Fig. 1). Roughly 80% of the U.S. rice exports to Mexico consist of paddy rice. There is great concern among industry leaders about the potential retaliation measures Mexico may take if the White House proceeds with the proposed import tax.

Although it is too early to speculate how the Mexican government will respond to the trade sanction measure being proposed by the current U.S. administration, we

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assess the impact of two possible scenarios, namely: (1) Mexico retaliates imposing a 20% tax on imports from the U.S., and (2) Mexico retaliates by imposing a full ban on U.S. rice imports.

Procedures

We use a partial, spatial, supply chain model of the global rice economy (RiceFlow) to conduct the assessment. RiceFlow captures prices and costs associated with bilateral rice trade flows among all rice exporters and importers (Durand-Morat and Wailes, 2010). This framework has been used in a number of studies to demonstrate the benefits and costs of regional trade agreements for the U.S. sector (Durand-Morat and Wailes, 2016). We calibrate RiceFlow to the latest benchmark corresponding to calendar year 2013. Two scenarios are analyzed to evaluate the impact of Mexico retaliation: 1) a 20% import tariff on U.S. rice exports, and 2) a complete ban on U.S. rice exports. The RiceFlow model provides estimates of the impact on U.S. exports to Mexico and to other countries, as well as identifying the response of the Mexican rice sector and other export competitors who benefit by taxing imports of rice from the U.S. This analysis generates impacts on both volumes and prices. Economy-wide impacts including change in value of total output, value-added and employment using input-output multipliers developed for the U.S. rice sector (Harrison and Outlaw, 2010).

Results and Discussion

Scenario 1: Mexico retaliates imposing a 20% tax on imports from the U.S.

United States rice exports to Mexico are expected to drop by 24.9% driven by a 20.7% decrease in long-grain paddy exports and a 53.7% decrease in long-grain milled exports. Although the U.S. is expected to find alternative markets overseas, total U.S. long-grain rice exports still decrease by 5.2%. Lower exports will more than offset a marginal increase in domestic consumption, and push U.S. long-grain rice volume and value of production down by 2.4% and $67.1 million a year, respectively.

Mexico will partially offset the decrease in trade with the U.S. with larger imports from Mercosur (the Common Market of the South; primarily Uruguay) and Asia (primarily Pakistan). Still, total rice imports by Mexico are expected to decrease by 9.1%. The decreased competitiveness of U.S. rice in the Mexican market will boost domestic rice production in Mexico by 27.8%, which is expected to maintain total domestic consumption basically unchanged from the baseline situation.

Based on the modeling results, we estimate the economy-wide impact of the 20% import tariff on U.S. rice imposed by Mexico using the input-output multipliers generated by Harrison and Outlaw (2010). Total U.S. output, value added, and employment are expected to decrease by $99 million, $48 million, and 677 jobs, respectively (Fig. 2). Taking the share of rice production by state as a reference, we estimate the impact for Arkansas to amount to a loss of $35 million and $14 million of total output and value added, respectively, and 229 jobs (Fig. 3).

Scenario 2: Mexico retaliates by imposing a full ban on U.S. rice imports

Total U.S. rice exports are estimated to decrease by 12.6% as a result of a 20.7% decrease in long-grain rice exports and 12.0% increase in medium-grain rice exports. Lower long-grain exports drive U.S. long-grain rice production, both in volume and value, down by 8.7% and $238 million a year, respectively. The output volume and value of medium-grain rice increase by 5.5% and $29 million a year, respectively.

Mexico's rice market will be greatly affected by the ban on U.S. rice. The price of rice will increase by 38.0%, but given the inelastic nature of rice demand, total consumption will decrease only 1.6%. Despite the significant increase in rice imports from Mercosur (primarily Uruguay) and Asia (primarily Pakistan), total rice imports by Mexico are expected to decrease by 33.7%. The ban of U.S. rice in the Mexican market will boost domestic rice production in Mexico by 60.7%.

Using the input-output multipliers generated by Harrison and Outlaw (2010), we estimate the economy-wide impact of the Mexican ban on imports of U.S. rice. Total U.S. output, value added, and employment are expected to decrease by $347 million, $168 million, and 2365 jobs, respectively (Fig. 2). Taking the share of rice production by state as a reference, we estimate the impact for Arkansas to amount to a loss of $123 million and $49 million of total output and value added, respectively, and 800 jobs (Fig. 3).

Significance of Findings

The Mexican rice market is critically important to the U.S. rice sector. The analysis provided in this study offers estimates that reflect the economic harm to the U.S. rice sector that would be associated with retaliatory trade sanctions imposed by Mexico. Rice producers, processors, policy decision-makers will benefit from being aware of the benefits of the Mexican market for the U.S. rice industry and the costs that would be incurred if this market becomes sanctioned.

Acknowledgments

We acknowledge support from the Arkansas Rice Research and Promotion Board, the University of Arkansas System Division of Agriculture and U.S. Department of Agriculture, Hatch Project No. ARK02426.

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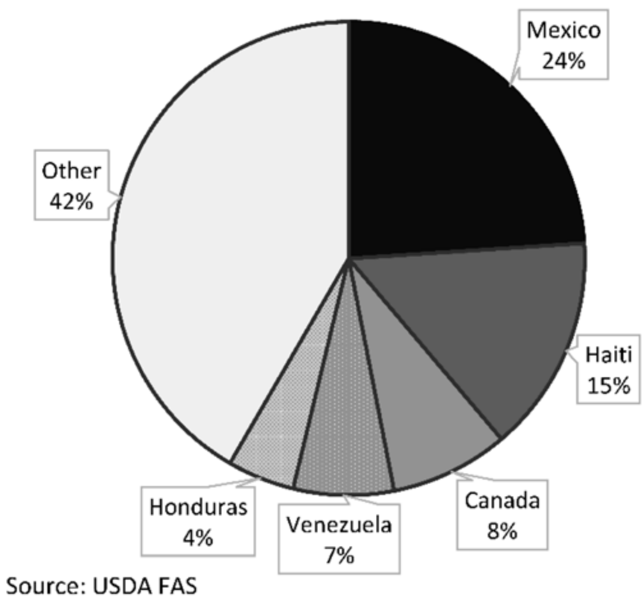

Fig. 1. Market share of U.S. long-grain rice exports, 2012-2016.

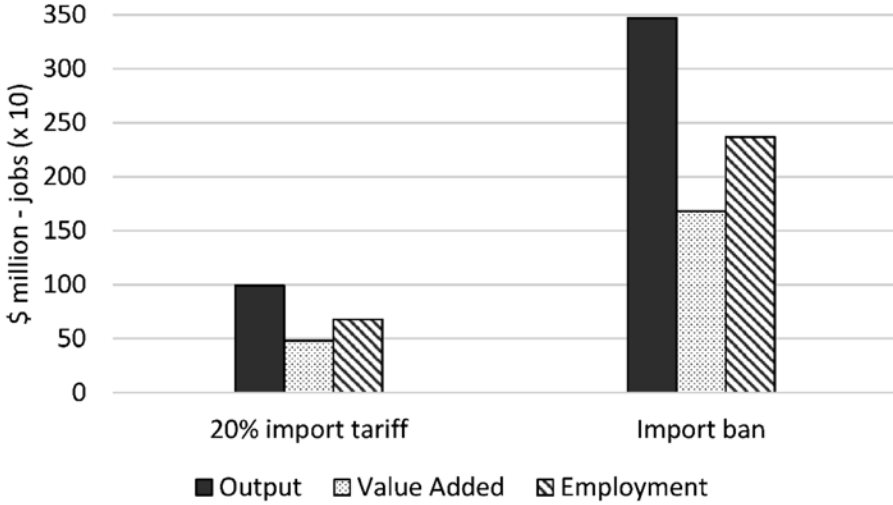

Fig. 2. Impact of a 20% tax and a ban on U.S. imports by Mexico on the U.S. economy.

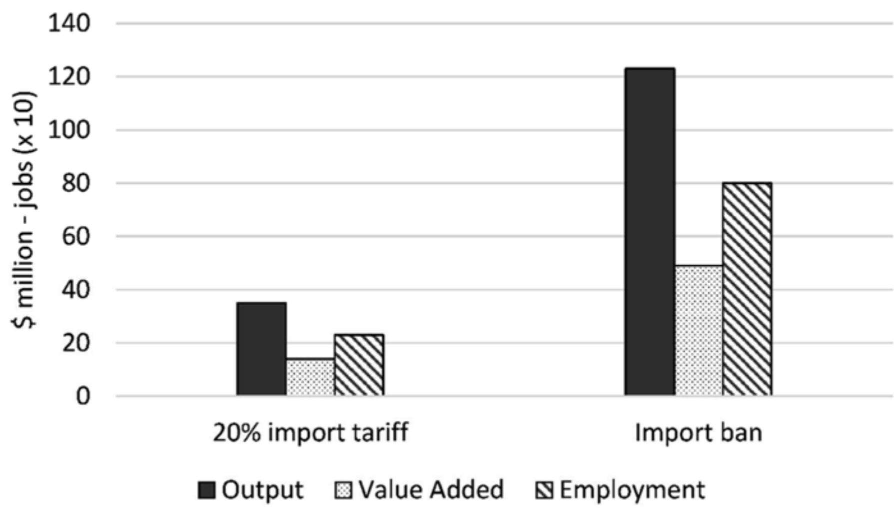

Fig. 3. Impact of a 20% tax and a ban on U.S. imports by Mexico on the Arkansas economy.

Economic Analysis of the University of Arkansas System Division of Agriculture Rice Foundation Seed Program: Cost and Price

R.U. Mane[1] and K.B. Watkins[1]

Abstract

The Foundation Seed Program for rice at the University of Arkansas System Division of Agriculture is a public breeding program used to multiply breeders' seed and provide quality seed to producers at a reasonable cost. An economic analysis of the Foundation Seed Program helps us to identify key input costs used in the production system. The cost structure is important for financial sustainability of the program. Production expenses for the rice foundation seed program are 163% larger than those for commercial rice production. Expenses for fertilizer, herbicide, insecticide, and fungicide application are much higher for rice foundation seed, reflecting the need to ensure clean and high quality seed production. Expenses related to machinery fuel and repairs and maintenance are also much larger for the rice foundation seed program, reflecting the use of much older and smaller equipment relative to commercial rice production. Prices charged by the program for Arkansas rice foundation seed are comparable to those charged by foundation seed programs in neighboring rice states.

Introduction

The objective of the Arkansas Foundation Seed Program is to multiply breeders' seed or any cultivar with the highest purity and supply quality seed to certified seed growers and ultimately to commercial producers at a reasonable cost. The University of Arkansas System Division of Agriculture administers the Arkansas Foundation Seed Program. The foundation seed production and processing facility for rice is located at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC), Stuttgart. The objectives of this research were to calculate the cost of producing rice foundation seed and to compare Arkansas rice foundation seed prices to those charged in other neighboring rice-producing states.

In the past three decades, the public breeding program for rice in Arkansas has resulted in higher yields, increasing annually by 0.68 bu/acre from 1983 to 2007 (Nalley et al. 2011). In general, the public breeding programs often undertake research not

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pursued by commercial breeding programs and labs in order to differentiate themselves and be competitive in the seed market (Carena, 2013). A similar case can be made for other foundation seed programs breeding high yielding pure-line, long- and medium-grain cultivars in neighboring rice-producing states (Louisiana, Mississippi, and Texas). The costs and resources involved in production of foundation seed increases overtime but the price of seed may not increase accordingly. Therefore, it is imperative to understand the cost of production for a foundation seed program as it can change over time. In other words, a better understanding of cost of production is important for financial sustainability of the foundation seed program (Worzella and Nargaard, 1957).

Procedures

Expenses for production of rice foundation seed were estimated using actual input amounts applied to foundation seed fields, input prices and custom application costs from 2016 University of Arkansas System Division of Agriculture's Crop Enterprise Budgets (Flanders and Watkins, 2016), and the actual machinery and equipment complement used in the rice foundation seed program at the RREC. Machinery variable and fixed expenses were calculated for actual existing machinery and equipment using American Society of Agricultural and Biological Engineers (ASABE) standard formulas and recommendations (ASABE, 2006, 2009). Phone interviews were conducted in 2016 to determine prices charged for rice foundation seed in the neighboring states of Louisiana, Mississippi, and Texas and to see how these prices compare with those charged for Arkansas rice foundation seed.

Results and Discussion

Production expenses for rice foundation seed are compared with commercial rice in Table 1. Production expenses for commercial rice were obtained directly from Arkansas Crop Enterprise Budgets for 2016 (Flanders and Watkins, 2016) and represent commercial rice production expenses in this study.

Operating expenses for rice foundation seed are nearly double those for commercial rice ($812.95/acre for rice foundation seed; $409.73 per acre for commercial rice, Table 1). The higher production expenses for foundation seed reflect the need to ensure clean and high quality seed is produced. This is reflected in the higher cost of such items as phosphate (P), potash (K), herbicide, insecticide, and fungicide, as well as the higher cost for custom application of these inputs for foundation seed production relative to commercial rice production. Other expenses included with the rice foundation seed budget but not with the commercial rice budget are poultry litter ($43.47/acre) and rogueing ($222.00/acre). Poultry litter is an important source of organic P and K that contains many micronutrients, and use of poultry litter is common in rice production based on its availability (Norman et al., 2013). However, rogueing is not a practice commonly used by commercial rice producers. The rogueing operation is responsible for removal of weeds using manual labor to maintain foundation seed that is free of noxious weeds and off-type seeds. There is zero tolerance for noxious weeds under the phyto-sanitary protocol set by the Arkansas Plant Board (Wilson et al., 2013). Rogueing alone accounts for 27% of the production expenses for rice foundation seed.

Other differences between commercial and rice foundation seed budgets are related primarily with machinery and equipment (Table 1). Machinery expenses related to fuel and to repairs and maintenance are much higher for the rice foundation seed budget than for the commercial budget. These expenses are higher because the rice foundation seed program operates with used equipment that is old and purchased at a fraction of the cost of new equipment. This machinery and equipment are also smaller and less efficient than what is generally used in commercial rice production. In contrast, machinery and equipment fixed expenses are much lower for the rice foundation seed program than for commercial rice. This again is due to much older machinery and equipment used in the rice foundation seed program. Older machinery and equipment translates into smaller depreciation expenses.

Sales prices for Arkansas rice foundation seed are compared with those from other rice-producing states in Table 2. Based on personal communication with program managers (R. Zaunbrecher from Louisiana, R. Vaughan Mississippi, and R.S. Brown from Texas) responsible for their respective foundation seed programs in Louisiana, Mississippi, and Texas, the current prices for rice foundation seed ranges from a minimum of $33.50/unit in Louisiana to maximum of $50.00/unit in Texas, with a unit equivalent to a 50-lb bag of seed. The price of foundation seed in Arkansas is $40.00/unit whereas Louisiana and Mississippi have $33.50 and $40.00/unit respectively (pers. comm.). In Texas, there is variable pricing of foundation seed. If the cultivar release date is greater than 5 years old, the price is $37.50/unit. However, if the cultivar has been recently released within a 5 year period, the price is $50/unit (pers. comm. Rich Zaunbrecher, Randy Vaughan, and R. Steven Brown).

Rice foundation seed prices have remained unchanged for all states for the past 5 years. Foundation seed pricing differs from that of the seed industry, which uses pricing based on seed count rather than weight. Also, the seed industry generally uses life-cycle analysis of a cultivar as a metric to maximize revenue from a newly released cultivar. The commercial longevity of seed is important to maximize revenue that can both offset the cost of seed production and contribute additional revenue to the commercial seed facility. However, the current University of Arkansas System Division of Agriculture's Foundation Seed Program has a fixed price irrespective of the demand or popularity for a particular cultivar. In other words, the University of Arkansas System Division of Agriculture's Foundation Seed Program prices all foundation seed the same, which is often not the case with commercial seed production businesses.

Significance of Findings

The cost estimates found in this study are imperative to understand the factors behind the cost of production for the Foundation Seed Program. Input costs are higher for foundation seed when compared to commercial production, as the objective of the

Foundation Seed Program is to have the best seed that is superior in quality and vigor. Similarly, there are higher costs for herbicide, fungicide and insecticides. However, two important costs that the foundation seed program has over commercial rice production are 1) higher fuel and repair and maintenance expenses for machinery and equipment, and 2) the use of rogueing to control noxious weeds. Therefore, managing the above-mentioned costs is important to the financial sustainability of the Foundation Seed Program.

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Table 1. Production expenses of rice foundation seed compared with commercial rice, 2016 dollars.

Operating expenses	Foundation seed rice $/acre	Foundation seed rice Percent	Commercial rice[a] $/acre	Commercial rice[a] Percent	Difference $/acre
	($/acre)	(%)	($/acre)	(%)	($/acre)
Seed	30.55	4	33.84	8	-3.29
Nitrogen	65.18	8	59.40	14	5.78
Phosphate	46.00	6	20.00	5	26.00
Potash	44.40	5	20.00	5	24.40
Sulfur	---	---	---	---	---
Boron	---	---	---	---	---
Agrotain	---	---	8.38	2	-8.38
Chicken litter	43.47	5	---	---	43.47
Herbicide	81.81	10	68.41	17	13.40
Insecticide	7.19	1	3.63	1	3.56
Fungicide	47.21	6	27.50	7	19.71
Other chemical	---	---	---	---	---
Custom ground application	12.00	1	0.00	0	12.00
Custom air application	31.00	4	21.00	5	10.00
Custom air application (lb)	25.58	3	23.10	6	2.48
Other custom hire, air seeding	---	---	---	---	---
Diesel fuel, pre-harvest machinery	31.10	4	7.95	2	23.15
R&M[b], pre-harvest machinery	29.04	4	6.34	2	22.70
Diesel fuel, harvest machinery	3.12	0	6.77	2	-3.65
R&M, harvest machinery	22.36	3	11.58	3	10.78
Irrigation energy cost	61.63	8	67.33	16	-5.70
Irrigation system R&M	3.85	0	7.09	2	-3.24
Supplies (ex. polypipe, levee gates)	0.98	0	0.65	0	0.33
Survey levees	4.50	1	4.50	1	0.00
Other (rogueing)	222.00	27	---	---	222.00
Operating interest	---	---	12.27	3	-12.27
Total operating expenses	812.95	100	409.73	100	403.22
Fixed expenses					
Machinery and equipment	20.79		73.88		
Irrigation equipment	21.72		35.98		
Farm overhead	1.78		4.59		
Total fixed expenses	44.29		114.46		
Total expenses	857.24		524.19		

[a] Commercial rice costs obtained from the Arkansas 2016 Crop Enterprise Budgets (Flanders and Watkins, 2016).

[b] R&M = repairs and maintenance.

Table 2. Sales prices of rice foundation seed in Arkansas, Louisiana, Mississippi, and Texas, 2010-2016.

				Texas[a]	
Year	Arkansas	Louisiana	Mississippi	5 or more years	Less than 5 years
	($/50 lb bag)				
2010	30.00	31.00	36.00		
2011	40.00	31.00	40.00		
2012	40.00	31.00	40.00	37.50	50.00
2013	40.00	33.50	40.00	37.50	50.00
2014	40.00	33.50	40.00	37.50	50.00
2015	40.00	33.50	40.00	37.50	50.00
2016	40.00	33.50	40.00	37.50	50.00

[a] "5 or more years" = cultivar release date is 5 or more years old. "Less than 5 years" = cultivar release date less than 5 years old.

Source: Personal communication (2016) with each state's respective foundation seed program manager (R. Zaunbrecher, from Louisiana; R. Vaughan, from Mississippi; and R.S. Brown, from Texas).

World and United States Rice Baseline Projections, 2016-2027

E.J. Wailes[1] and E.C. Chavez[1]

Abstract

International rice prices have declined in 2016/17 due to weaker import market demand. Over the next decade, however, we project the baseline average global rice price to increase steadily at 2.6% annually, as total global trade grows at 1.5% over the same period. The high concentration of export supply from only a few countries however also suggests that international rice prices will remain volatile into the future. India and Thailand remain the top rice exporters; and the People's Republic of China (PRC) and Nigeria remain the major importers. Cambodia, Myanmar, Thailand, and Vietnam account for most of the expected growth in exports over the next decade. Consumers in Western African countries and the Middle East account for most of the import demand growth. We project the United States to remain the fifth largest rice exporter in the world, with half of U.S. rice output shipped to international markets. Improvement in yields, based on enhanced genetics and more efficient farming and processing technologies, will account for the growth in global rice output, as production area shows no growth. Production subsidies in a number of countries will likely continue to support achievement of self-sufficiency (USA Rice Federation, 2014). Assuming normal weather patterns, we project adequate global rice supplies. Population growth drives increases in global rice consumption, as per capita use declines at 0.2% annually. Baseline global rice stocks expand by 1.5% per year, with growth mainly from the PRC.

Introduction

This report presents baseline rice projections from the Arkansas Global Rice Economics Program (AGREP) with the University of Arkansas System Division of Agriculture Department of Agricultural Economics and Agribusiness in 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 factors that determine potential supply, demand, and price behavior.

Thailand, India, Vietnam, Pakistan, and the United States remain the top exporters in the international rice market, accounting for about 80% of world export supply.

[1] L.C. Carter Distinguished Professor and Program Associate III, respectively, Department of Agricultural Economics and Agribusiness, Fayetteville.

Thailand lost its long-time global export leadership to India when the former implemented the controversial and costly paddy pledging program (PPP) in 2011, a price-floor support policy for Thai farmers (Wailes and Chavez, 2013). This policy made Thai rice uncompetitive in world trade and resulted in excessive rice stock accumulation. The country's rice sector has slowly recovered since the military government came to power and suspended the PPP in 2014. A drought in 2016 also helped reduce excess supplies. The PPP was replaced with reduced market intervention price support for fragrant and glutinous paddy, down from $571/metric ton (mt) to $469/mt and through the On-Farm Paddy Pledging program, which encourages stockpiling rice by Thai farmers, and the Interest-Rate Subsidy Program to encourage millers, traders, and farmers to hold production at harvest for 4 to 6 months of storage. In 2016, the government adjusted the intervention support price for all types of rice, downward to $271/mt for fragrant (Hom Mali) and glutinous paddy, to $234/mt for Pathumthani fragrant paddy and to $200/mt for non-fragrant paddy (USDA-FAS, 2017a). Despite a relatively large accumulation of rice, the Thai government has been slowly disposing of the stocks, mindful of its adverse impact on international prices. Given the country's strong rice infrastructure, this baseline projects that Thailand will regain its dominant role in global exports by 2017.

Procedures

The baseline estimates presented in this report are generated using the Arkansas Global Rice Model (AGRM), a partial equilibrium, non-spatial, multi-country/regional statistical simulation and econometric framework that covers 66 rice-producing and consuming countries/regions developed and maintained by AGREP.

Most of the details and the theoretical structure and the general equations of the AGRM, with the exception of the newly added countries, can be found in the online documentation by Wailes and Chavez (2011). The historical rice data comes from USDA-FAS (2017b) and USDA-ERS (2017); and the macro data comes from IHS Global Insight provided by the Food and Agriculture Policy Research Institute (FAPRI)-Missouri. The baseline projections are grounded in a series of assumptions as of January 2017 about the general economy, agricultural policies, weather, and technological change. The basic assumptions include the following: continuation of existing policies; current macroeconomic variables; no new World Trade Organization trade reforms; and average normal weather conditions.

Results and Discussion[2]

International rice prices have weakened in 2016/17 due to reduced demand from traditional market destinations. Over the next decade, the average global rice price is projected to increase steadily at 2.6% annually, as total global trade grows at 1.5%

[2] Although complete baseline projections for supply and demand variables are generated for all 66 countries/regions covered by AGRM, only selected variables are included in this report due to space consideration.

over the same period. Major rice-deficit countries continue to resort to importation as domestic production falls short of domestic demand despite efforts and expressed desire to attain self-sufficiency. The average long-grain rice international reference price increases from $392/mt (2014-2016 average) to $520/mt in 2027 (Table 1). Over the same period, international medium-grain rice prices are projected to sustain a relatively high level, ranging between $753/mt (2014-2016 average) and $743/mt, as segmentation increases in trade flows and prices of long- and medium-grain markets.

While convergence between the Thai prices and the international market prices has resumed, Western Hemisphere prices were substantially higher—with average margins to Asian prices reaching as high as $151/mt in 2015—which has proven unsustainable. Margins have narrowed since then and are projected to decline steadily, reaching $35 in 2021 and $15 by 2027, the end of the projection period (Table 1). The narrowing margin is consistent with the expected increasing inroads of Asian rice, particularly from Vietnam, into the Latin American markets.

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. On average, these two countries combined account for 36% of the world population from 2016-2027. Over the same period, they will have an average combined share of 45% of world rice area harvested, 51% of total milled rice production, 50% of total rice consumption, and 75% of world rice stocks.

Global 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 focused self-sufficiency programs of major consuming countries. World production expands by a net of 48.5 million metric tons (mmt) over the next decade, equivalent to an annual growth of 0.9%; and reaching 526.2 mmt in 2027 with 0.8% coming from yield improvement and 0.1% coming from growth in area harvested (Table 2).

By volume, 29% of the expected growth in global rice output over the same period will come from India; 39% from seven countries that include Bangladesh, Thailand, Vietnam, Indonesia, Myanmar, Cambodia, and the Philippines combined; and 9.0% from the 15-member Economic Community of West African States (ECOWAS). The rice output of PRC, however, declines by 715 thousand mt, and those of Japan and South Korea decline by 1.3 mmt combined, over the same period. Total U.S. rice production, on the other hand, is projected to increase by a total of about 1.2 mmt or 38 million hundred weight (cwt) over the same period, equivalent to 1.5% annual growth, which comes mainly from yield improvement (Table 3).

World rice consumption growth over the next decade is driven by income, population, and other demographic variables. Rising incomes dampen rice demand in some Asian countries where rice is an inferior good. These countries include Japan, Taiwan, PRC, and South Korea. 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 49.5 mmt reaching 524.2 mmt in 2027, equivalent to an annual growth of 0.9%—with global population growth of 1.1% per year projected to be offset partly by a 0.2% decline in average world rice per capita use (Table 2).

About 24% of the total global growth in rice consumption by volume is accounted for by India; 27% by the five countries of Bangladesh, PRC, the Philippines, Indonesia, and Vietnam combined; and 18% by ECOWAS. United States rice consumption increases by nearly 524 thousand mt (tmt, 16.9 million cwt) over the same period, reaching 4.6 mmt (143.6 million cwt) in 2027 or an annual growth of 1.1%, of which 0.8% comes from population growth and 0.3% from per capita use. Global rice stocks-to-use ratio is projected to range between 0.20-0.25 over the projection period.

Total global rice trade expands 1.5% per year, reaching 48.6 mmt in 2027 from an average 41.4 mmt during the period 2014-16 (Table 1). On the exporters' side, the significant investment in production and processing capacity in the Mekong Delta in Vietnam, Cambodia and Myanmar bodes well for these countries' increasing role as important rice suppliers in the coming years. As low-cost producers, these countries are situated geographically to supply the steady 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.

Thailand is projected to resume and maintain its 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 long-grain and aromatic rice markets. For the U.S., total rice exports expand by 785 tmt or 25.0 million cwt over the next decade, reaching 4.1 mmt (or 130 million cwt) in 2027; and total imports grow by 34 tmt (or 1.0 million cwt), reaching 771 tmt (or 25 million cwt) in 2027. For reference purposes, a detailed U.S. rice supply and use in rough basis and English units is presented in Table 3. Cambodia's exports are projected to expand at 7.5%/year, reaching 2.2 mmt in 2027 as growth in both area and yield give rise to consistent surplus production. Myanmar's exports, on the other hand, are projected to expand from 1.4 mmt (2014-16 average) to 2.8 mmt in 2027, supported solely by yield-based growth in production.

On the demand side, while China remains an important major rice importer over the next decade, the country's imports are relatively flat around the tariff-rate quota (TRQ) level as it maintains a reasonable rice stockpile consistent with its food security goal and storage capacity. Nearly 78% of the growth in global net imports by volume will come from Africa, with ECOWAS accounting for 58% 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.

Significance of Findings

The Arkansas rice stakeholders will certainly benefit from an understanding of the market and policy forces that drive the global rice market. This is especially true because Arkansas is the top rice-producing state in the U.S., accounting for 49% of the country's rice output. Since nearly half of Arkansas's 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. These numbers could also serve as baseline reference for further analysis involving impacts of alternative policies and market shocks. 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

Country	2014/ 2015	2015/ 2016	2016/ 2017	2017/ 2018	2018/ 2019	2019/ 2020
	----------	----------	----------	----------	----------	----------
Net exporters						
Argentina	307	555	529	533	495	503
Australia	153	-20	79	75	55	56
Cambodia	1130	870	951	902	1008	1146
Lao PDR	-154	-145	-88	-91	-74	-69
Egypt	216	100	272	274	277	283
India	12,238	10,240	10,039	10,087	10,106	10,110
Myanmar (Burma)	1727	1060	1316	2046	1732	1821
Pakistan	3770	4290	4077	3721	3742	3622
Thailand	9479	9200	9370	10,145	10,088	10,054
United States	2278	2655	2788	2793	2897	2902
Uruguay	766	930	869	852	868	874
Vietnam	6206	4800	5335	5234	5356	6176
Brazil	538	-200	-392	-334	-166	27
Paraguay	410	478	492	476	522	546
Total net exports[a]	39,064	34,813	35,637	36,713	36,905	38,049
Net importers						
Bangladesh	1226	213	225	745	575	524
People's Republic of China	4274	4529	4637	4588	4493	4420
Brunei Darussalam	43	48	51	50	51	52
Cameroon	525	530	530	534	545	579
Canada	358	348	372	369	387	399
China - Hong Kong	332	340	353	353	358	365
Columbia	300	302	252	239	253	274
Cote d'Ivorie	1270	1175	1190	1243	1231	1203
European Union-28	1434	1531	1519	1487	1504	1536
Ghana	585	650	663	680	680	684
Guinea	300	400	434	421	412	395
Indonesia	1350	1100	1303	1140	1042	1376
Iran	1350	1100	1126	1228	1329	1374
Iraq	1161	900	1014	1043	1069	1102
Japan	565	620	602	602	602	602
Kenya	420	460	461	476	503	558
Liberia	340	200	310	301	309	331
Malaysia	978	900	929	996	1030	1033
Mali	180	170	200	140	90	97
Mexico	707	691	743	744	766	779
Mozambique	615	550	598	610	631	652
Nigeria	2600	2100	2273	2687	2793	2929
Philippines	1800	1600	1469	1795	1709	1864
Saudi Arabia	1600	1500	1564	1649	1683	1709
Senegal	1190	990	935	980	1103	1032
Sierra Leone	220	200	206	186	161	164

international reference prices, 2014-2027 (milled basis).

2020/ 2021	2021/ 2022	2022/ 2023	2023/ 2024	2024/ 2025	2025/ 2026	2026/ 2027	2027/ 2028
(thousand metric tons) ----------							
522	538	551	563	586	600	612	624
55	57	60	65	67	64	60	51
1270	1401	1587	1759	1850	1993	2052	2196
-68	-48	-21	16	45	76	108	135
297	308	316	320	321	320	316	311
9922	9887	9869	9888	9894	10,005	10,210	10,298
1902	2021	2101	2251	2391	2445	2553	2717
3591	3639	3692	3716	3765	3777	3824	3838
10,373	10,213	10,037	10,252	10,232	10,575	10,728	10,939
2974	3044	3114	3150	3221	3277	3314	3324
880	900	918	936	951	974	993	1006
6427	6538	6590	6667	6776	6760	6814	6886
117	167	281	330	387	452	542	607
550	577	603	633	665	707	746	792
38,811	39,243	39,699	40,546	41,152	42,025	42,874	43,273
559	615	636	625	719	853	1008	1023
4360	4313	4268	4231	4204	4172	4130	4095
52	52	52	53	53	54	55	56
591	600	612	617	629	666	699	739
407	415	421	429	434	441	447	454
370	374	379	384	388	393	397	401
281	292	289	298	309	319	329	345
1205	1199	1155	1178	1206	1181	1214	1306
1556	1576	1593	1611	1626	1643	1646	1653
686	687	686	682	676	678	677	683
394	369	365	361	330	314	296	295
1534	1417	1368	1540	1568	1666	1667	1691
1407	1452	1499	1532	1560	1638	1660	1730
1131	1163	1197	1246	1302	1352	1419	1480
602	602	602	602	602	602	602	602
565	612	626	665	679	721	739	783
338	350	357	367	370	382	392	406
1034	1001	992	986	976	962	960	954
94	111	108	114	98	103	110	135
788	802	812	822	834	843	850	859
672	695	720	749	778	812	843	880
3111	3196	3326	3503	3678	3839	4033	4165
1927	1931	1949	1926	1894	1887	1892	1830
1765	1805	1839	1875	1909	1943	1973	2003
1051	1078	1128	1171	1215	1255	1300	1352
160	168	156	156	156	160	167	176

continued

Table 1. Continued.

Country	2014/ 2015	2015/ 2016	2016/ 2017	2017/ 2018	2018/ 2019	2019/ 2020
	-----------	-----------	-----------	-----------	-----------	-----------
Net importers (continued)						
Singapore	288	300	312	315	320	325
South Africa	863	824	911	942	960	977
South Korea	463	338	409	409	409	409
Taiwan	47	36	36	36	36	36
Tanzania	145	150	123	217	206	242
Turkey	292	200	280	268	263	258
Other Africa	1960	1752	1825	1833	1878	1933
Other Americas	518	502	605	486	493	496
Other Asia	4049	3042	3514	3133	3231	3316
Other Europe	118	125	143	129	135	143
Other Oceania	45	66	25	26	28	29
ECOWAS 7	1361	1532	1561	1616	1699	1805
Madagascar	200	180	233	287	317	344
Malawi	15	15	17	16	19	22
Zambia	10	10	11	11	14	16
Rwanda	40	40	43	46	48	52
Uganda	80	80	85	85	95	103
Cuba	483	524	515	505	510	519
Costa Rica	125	155	111	126	128	132
Dominican Republic	13	20	78	100	71	58
Guatemala	85	90	93	92	94	97
Honduras	112	219	157	158	160	163
Nicaragua	65	117	58	79	78	79
Panama	76	102	93	90	99	102
Chile	126	134	129	129	131	134
Peru	178	212	234	210	168	117
Residual	1584	901	78	83	107	111
Total net imports	39,064	34,816	35,637	36,713	36,905	38,049
Prices	-----------	-----------	-----------	-----------	-----------	-----------
International rice reference price	420	386	369	415	430	421
U.S. FOB[b] Gulf Ports	518	537	467	470	473	472
U.S. No. 2 Medium FOB Calif.	911	768	579	706	714	720

[a] Total net exports are the sum of all positive net exports and negative net imports.
[b] FOB = free on board.

2020/ 2021	2021/ 2022	2022/ 2023	2023/ 2024	2024/ 2025	2025/ 2026	2026/ 2027	2027/ 2028
(thousand metric tons) ----------							
328	332	332	333	333	334	334	335
985	994	995	1016	1000	1029	1044	1071
409	409	409	409	409	409	409	409
36	36	36	36	36	36	36	36
276	290	292	301	308	314	318	331
253	252	249	247	246	245	244	242
1985	2035	2090	2142	2203	2251	2304	2360
511	517	524	535	527	535	554	559
3237	3228	3217	3231	3179	3119	3079	3041
148	148	149	151	152	154	155	157
30	30	30	30	30	29	29	28
1901	1984	2062	2124	2200	2272	2368	2472
373	406	443	484	525	566	606	644
25	28	31	34	37	40	43	47
18	19	19	20	21	23	25	26
58	60	65	70	74	81	85	91
110	117	125	135	144	155	165	177
520	515	511	514	510	509	503	502
136	138	139	140	142	143	144	146
52	47	44	42	42	40	39	38
100	103	106	110	113	116	119	123
163	165	168	172	175	178	181	184
79	78	77	77	76	76	75	76
105	107	107	109	109	108	107	107
138	139	140	143	145	148	152	156
79	70	79	84	105	114	420	127
115	121	125	125	121	121	130	146
38,811	39,243	39,699	40,546	41,152	42,025	42,874	43,723
(U.S. dollars/metric tons) ----------							
435	453	471	477	494	501	515	520
476	488	498	503	512	518	531	535
721	728	733	737	739	740	742	743

Table 2. World rice supply and utilization,

Country		**2014/ 2015**	**2015/ 2016**	**2016/ 2017**	**2017/ 2018**	**2018/ 2019**
	(units)	------------	------------	------------	------------	------------
Area harvested	(1000 ha)	160,928	159,237	161,777	160,687	161,463
		------------	------------	------------	------------	------------
Yield	(mt/ha)	2.97	2.97	2.98	3.02	3.05
		------------	------------	------------	------------	------------
Production	(1000 mt)	478,553	482,387	482,253	484,729	491,781
Beginning stocks	(1000 mt)	113,871	114,662	116,508	118,751	121,087
Domestic supply	(1000 mt)	592,424	587,049	598,761	603,480	612,868
Consumption	(1000 mt)	475,315	468,829	479,933	482,310	488,013
Ending stocks	(1000 mt)	114,662	116,508	118,751	121,087	124,748
Domestic use	(1000 mt)	589,977	585,337	598,684	603,397	612,761
Total trade	(1000 mt)	43,582	39,669	40,973	42,135	42,172
Stocks-to-use	(ratio)	0.19	0.20	0.20	0.20	0.20
Per capita use	(kg)	65.63	64.00	64.78	64.39	64.45
Population growth	(%)	1.17	1.15	1.13	1.12	1.09
Real GDP growth	(%)	2.77	2.74	2.44	2.82	3.09

Table 3. Detailed U.S. rice supply and utilization,

Variable		**2014**	**2015**	**2016**	**2017**	**2018**
	(units)					
Yield	(lb/acre)	7576.4	7472.0	7237.0	7779.0	7841.2
Total harvested area	(1000 mt)	2933.0	2585.0	3097.0	2875.6	2898.2
Supply	(mil. cwt)	278.7	264.8	294.7	296.6	303.4
Production	(mil. cwt)	222.2	192.1	224.1	223.7	227.3
Beginning stocks	(mil. cwt)	31.8	48.5	46.5	48.9	52.2
Imports	(mil. cwt)	24.7	24.2	24.0	24.0	24.0
Domestic use (rough basis)	(mil. cwt)	134.5	111.6	134.0	132.4	133.8
Food	(mil. cwt)	108.8	96.0	107.2	108.3	109.5
Seed	(mil. cwt)	3.2	4.0	3.9	3.6	3.6
Brewing	(mil. cwt)	18.8	19.1	19.5	19.4	19.5
Residual	(mil. cwt)	3.7	-7.5	3.4	1.1	1.2
Exports	(mil. cwt)	95.7	107.7	111.8	112.0	115.2
Total use	(mil. cwt)	230.2	219.3	245.8	244.4	249.0
Ending Stocks	(mil. cwt)	48.5	46.5	48.9	52.2	54.5

and macro data, 2014-2027 (milled basis).

	2019/ 2020	2020/ 2021	2021/ 2022	2022/ 2023	2023/ 2024	2024/ 2025	2025/ 2026	2026/ 2027	2027/ 2028
(thousand hectares)									
	161,821	161,779	161,791	162,057	162,295	162,366	162,572	162,706	62,866
(mt/ha)									
	3.07	3.09	3.11	3.13	3.15	3.17	3.19	3.21	3.23
(thousand metric tons)									
	496,836	499,826	502,837	506,902	510,943	514,437	517,829	521,805	526,210
	124,748	127,920	129,525	130,169	131,196	132,114	133,251	133,944	135,251
	621,584	627,746	632,362	637,071	642,139	646,551	651,080	655,749	661,461
	493,553	498,106	502,072	505,750	509,900	513,178	517,015	520,368	524,240
	127,920	129,525	130,169	131,196	132,114	133,251	133,944	135,251	137,075
	621,473	627,631	632,241	636,946	645,013	646,430	650,959	655,619	661,315
	43,265	44,011	44,436	44,827	45,650	46,212	47,034	47,816	48,632
	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21
	64.49	64.42	64.28	64.12	64.03	63.84	63.73	63.57	63.48
	1.7	1.04	1.02	0.99	0.97	0.95	0.93	0.90	0.88
	3.08	3.05	3.14	3.18	3.14	3.11	3.04	3.01	3.00

and macro data, (rough basis in English units).

	2019	2020	2021	2022	2023	2024	2025	2026	2027
	7915.7	7985.6	8060.3	8130.1	8210.4	8290.3	8368.8	8441.9	8515.1
	2916.8	2930.7	2950.0	2967.5	2962.8	2963.0	2960.2	2953.3	2947.0
	309.9	317.4	625.1	332.4	338.4	344.5	350.1	355.1	359.8
	230.9	234.0	237.8	241.3	243.3	245.6	247.7	249.3	250.9
	54.5	58.6	62.3	65.9	69.7	73.5	77.2	80.6	83.5
	24.6	24.8	25.0	25.2	25.5	25.3	25.1	25.2	25.4
	135.3	136.7	138.3	139.4	140.2	140.5	141.1	142.0	143.6
	110.7	111.8	113.5	115.5	117.5	119.4	121.3	123.2	125.1
	3.6	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7
	19.6	19.7	19.8	19.8	19.9	20.0	20.1	20.1	20.1
	1.4	1.6	1.4	0.3	-0.8	-2.6	-3.9	-4.9	-5.3
	115.9	118.4	120.9	123.3	124.7	126.8	128.3	129.5	130.41
	251.3	255.1	259.2	262.7	264.9	267.2	269.5	271.6	273.7
	58.6	62.3	65.9	69.7	73.5	77.2	80.6	83.5	86.2

continued

Table 3. continued.

Variable	(units)	2014	2015	2016	2017	2018
Prices						
Loan rate	(US$/cwt)	6.50	6.50	6.50	6.50	6.50
Season ave. farm price	(US$/cwt)	13.40	12.10	10.25	11.31	11.29
Long-grain farm price	(US$/cwt)	11.90	11.10	9.56	10.29	10.36
Medium-grain farm price (ave.)	(US$/cwt)	18.30	15.30	12.93	14.60	14.63
Japonica farm price	(US$/cwt)	21.60	18.30	14.10	16.03	16.07
Southern medium-grain farm price	(US$/cwt)	14.40	11.20	10.36	11.87	11.94
Reference prices						
Long-grain farm price	(US$/cwt)	14.00	14.00	14.00	14.00	14.00
Southern medium-grain farm price	(US$/cwt)	14.00	14.00	14.00	14.00	14.00
Japonica	(US$/cwt)	16.10	16.10	16.10	16.10	16.10
Export price, FOB[a] Houston (U.S. No.	(US$/cwt)	23.50	24.36	21.19	21.33	21.47
Medium-grain price, FOB Calif (U.S. No.	(US$/cwt)	41.32	34.84	26.26	32.05	32.40
Program payment	(US$/cwt)	1.5	2.7	3.8	2.9	2.7
Average world price	(US$/cwt)	10.6	9.5	8.8	9.0	9.2
Income factors						
Production market value	(mil. US$)	3026.8	2394.2	2337.3	2545.9	2604.2
Program payments	(mil. US$)	337.8	514.1	855.3	640.5	623.3
Total income	(mil. US$)	3364.6	2908.2	3192.6	3186.4	3227.5
Market returns above variable cost	(US$/acre)	497.8	421.8	260.0	387.0	390.2
Total returns	(US$/acre)	613.0	620.6	536.2	609.8	605.2
Per capita use	(lb)	39.67	24.33	28.89	28.32	28.39
Stocks-to-use	(ratio)	0.21	0.21	0.20	0.21	0.22
Population growth	(%)	0.76	0.77	0.78	0.82	0.80
Real GDP growth	(%)	2.37	2.60	1.56	2.30	2.63

[a] FOB = free on board.

2019	2020	2021	2022	2023	2024	2025	2026	2027
6.50	6.50	6.50	6.50	6.50	6.50	6.50	6.50	6.50
11.34	11.45	11.64	11.81	12.00	12.29	12.42	12.73	12.93
10.40	10.51	10.69	10.90	11.11	11.38	11.51	11.80	12.00
14.67	14.78	14.98	15.04	15.17	15.38	15.53	15.81	16.00
16.14	16.29	16.52	16.54	16.70	17.04	17.17	17.54	17.76
12.00	12.12	12.30	12.52	12.72	13.04	13.18	13.51	13.74
14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00
14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00
16.10	16.10	16.10	16.10	16.10	16.10	16.10	16.10	16.10
21.39	21.60	22.13	22.61	22.82	23.23	23.50	24.09	24.25
32.66	32.70	33.00	33.26	33.43	33.51	33.57	33.68	33.68
2.7	2.5	2.4	2.2	2.0	1.8	1.7	1.5	1.3
9.1	9.3	9.5	9.8	9.9	10.1	10.3	10.5	10.6
2657.8	2719.9	2808.6	2890.8	2958.5	3050.0	3107.8	3198.3	3266.2
613.0	593.5	560.1	523.1	487.0	437.8	415.1	363.5	328.9
3270.8	3313.4	3368.7	3413.8	3445.5	3487.8	3522.9	3561.8	3595.1
389.6	313.2	316.9	318.1	323.3	338.3	341.6	361.5	373.2
599.7	313.2	316.9	318.1	323.3	338.3	341.6	361.5	373.2
28.49	28.56	28.67	28.67	28.63	28.47	28.40	28.37	28.49
0.23	0.24	0.25	0.27	0.28	0.29	0.30	0.31	0.31
0.80	0.79	0.78	0.77	0.75	0.74	0.73	0.72	0.70
2.30	2.08	2.17	2.18	2.10	1.97	1.84	1.85	1.95

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