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B. R. Wells Arkansas Rice Research Studies 2013

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B.R. Wells
ARKANSAS RICE RESEARCH STUDIES 2013

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

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DIVISION OF AGRICULTURE
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University of Arkansas System

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Cover Photo: Rice harvest on the Grand Prairie near Hazen, Ark.. Photo credit: University of Arkansas System Division of Agriculture.

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Research Studies
2013

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

DEDICATED IN MEMORY OF

Bobby R. Wells

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

Wells was a world-renowned expert on rice production with special emphasis on rice nutrition and soil fertility. He was very active in the Rice Technical Working Group (RTWG), for which he served on several committees, chaired and/or moderated Rice Culture sections at the meetings, and was a past secretary and chairman of the RTWG. He loved being a professor and was an outstanding teacher and a mentor to numerous graduate students. Wells developed an upper-level course in rice production and taught it for many years. He was appointed head of the Department of Agronomy in 1993 and was promoted to the rank of University Professor that year in recognition of his outstanding contributions to research, service, and teaching.

Among the awards Wells received were the Outstanding Faculty Award from the Department of Agronomy (1981), the Distinguished Rice Research and/or Education Award from the Rice Technical Working Group (1988), and the Outstanding Researcher Award from the Arkansas Association of Cooperative Extension Specialists (1992). He was named a Fellow in the American Society of Agronomy (1993) and was awarded, posthumously, the Distinguished Service Award from the RTWG (1998).

Wells edited this series when it was titled *Arkansas Rice Research Studies* from the publication's inception in 1991 until his death in 1996. Because of Wells' contribution to rice research and this publication, it was renamed the *B.R. Wells Rice Research Studies* in his memory starting with the 1996 publication.

FOREWORD

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

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

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

All authors are either current or former faculty, staff, or students of the University of Arkansas System Division of Agriculture, or scientists with the United States Department of Agriculture, Agricultural Research Service. For further information about any author, contact Agricultural Communication Services, (479) 575-5647.

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The Arkansas Rice Research and Promotion Board

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Trends in Arkansas Rice Production, 2013

J.T. Hardke

ABSTRACT

Arkansas is the leading rice-producing state in the United States. The state represents 42.6% of total U.S. rice production and 43.2% of the total acres planted to rice in 2013. 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 DD50 program was included to summarize variety acreage distribution across Arkansas. Other data was obtained from the USDA National Agricultural Statistics Service.

INTRODUCTION

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

PROCEDURES

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

RESULTS AND DISCUSSION

Rice acreage by county is presented in Table 1 with distribution of the most widely produced cultivars. RiceTec CLXL745 was the most widely planted cultivar in 2013 at 22.4% of the acreage, followed by Roy J (13.9%), Jupiter (10.0%), CL151 (9.7%), CL152 (7.8%), RiceTec CLXL729 (7.5%), RiceTec XL753 (6.2%), CL111 (6.0%), RiceTec XL723 (3.4%), and Wells (3.2%). Additional cultivars of importance in 2013, though not shown in the table, were Francis, Cheniere, Taggart, and Mermentau.

Arkansas planted 1,076,000 acres of rice in 2013 which accounted for 43.2% of the total U.S. rice crop in 2013 (Table 2). The state-average yield of 7,560 lb/acre (168 bu/acre) was a new state record yield and bested the previous record set in 2012 of 7,470 lb/acre (166 bu/acre). In addition, the 2013 average yield was a 1% increase in average yield from the 2012 crop. The average yields in Arkansas represented the third highest average in the U.S. behind California and Texas; the latter of which has a ratoon or second rice crop. The total rice produced in Arkansas during 2013 was 80.9 million hundredweight (cwt). This represents 43.2% of the 189.9 million cwt produced in the U.S. during 2013. Over the past 3 years, Arkansas has produced 44.4% of all rice produced in the U.S. The five largest rice-producing counties in Arkansas during 2013 included Poinsett, Lawrence, Arkansas, Lonoke, and Jackson; representing 35.5% of the state's total rice acreage (Table 1).

Planting in 2013 was behind the 5-year state average due to cold, wet conditions throughout March, April, and early May (Fig. 1). Planting progress was only 40% by 28 April in 2013 compared to an average of 62% planting progress by this date in previous years. Planting was almost fully complete by 2 June (over 2 weeks later than in 2012). While planting progress was notably delayed by early-season weather, mild and favorable weather conditions led to a more rapid harvest similar to the 5-year average (Fig. 2). About 43% of the crop was harvested by 22 September compared with 54% harvest progress on the same date in previous years. Harvest progress was nearly complete (96%) by 3 November.

Approximately 61% of the rice produced in Arkansas was planted using conventional tillage methods in 2013 (Table 3). This usually involves fall tillage when the weather cooperates, followed by spring tillage to prepare the seedbed. The remainder of rice grown was planted using stale seedbed (30.8%) or no-till (8.0%) systems. True no-till rice production is not common but is done in a few select regions of the state.

The majority (51.2%) of rice is still produced on silt loam soils (Table 3). Rice production on clay or clay loam soils (19.6% and 23.6%, respectively) has become static over recent years after steadily increasing through 2010. These differences in soil texture 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 71% of the rice acreage (Table 3). Approximately 21% of the acreage in 2013 was planted following rice, with the remaining 8% made up of rotation with other crops including cotton, corn, grain sorghum, wheat, and fallow. The majority of the rice in Arkansas was produced in a dry-seeded, delayed-flood system with only 3% using a water-seeded system. Annually, approximately 80% of all the Arkansas rice acreage was drill-seeded with the remaining 20% 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 was used to irrigate 79.3% of the rice acreage in Arkansas with the remaining 20.7% 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 2013, rice farmers utilized this practice on 34.4% of the rice acreage (Table 3). About 65% of rice is still irrigated with conventional levee and gate systems. A small percentage of rice acreage is produced in more upland conditions utilizing furrow or overhead irrigation systems.

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 2013, 28.3% of the acreage was burned, 40.2% was tilled, 29.6% was rolled, and 19.1% 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.

Pest management is vital to preserve both yield and quality in rice. Foliar fungicide applications were made on 54.0% of rice acres in 2013 (Table 3). This number was higher than in 2012 likely due to moderate temperatures, frequent rainfall, and cloudy weather late in the growing season for the northern half of the state which promoted disease development. Nearly 43% of rice acres received a foliar insecticide application due to rice stink bug infestation levels which were notably higher than in 2012.

Insecticide seed treatments were used on 61.0% 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 56% of the total rice acreage in 2013 (Fig. 3). This represents a 3% decrease in Clearfield rice acreage compared to 2012 and is only the third year since 2001 that plantings of Clearfield cultivars have decreased from the previous year. 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.

SIGNIFICANCE OF FINDINGS

During the past 20 years, the state average yields in Arkansas have increased approximately 2,060 lb/acre (about 46 bu/acre) or 2.3 bu/acre/year. 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 commercial field situations.

ACKNOWLEDGMENTS

The author would like to extend thanks to all of the county agents who participated in this study and the rice farmers of Arkansas who provide support through the rice check-off program.

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Table 1. 2013 Arkansas

	Harvested acreage[a]		Medium-grain		
County	2012	2013	Jupiter	Others[b]	CL111
Arkansas	88,891	71,885	5,433	44	1,666
Ashley	7,432	4,533	0	0	257
Chicot	26,443	25,107	0	0	1,424
Clay	77,474	64,740	5,953	54	938
Conway	1,715	1,704	0	0	0
Craighead	67,871	57,987	4,765	1,776	7,109
Crittenden	31,673	21,568	2,038	1,346	0
Cross	71,825	65,315	4,673	0	10,420
Desha	14,358	9,605	229	0	0
Drew	8,529	7,116	0	0	403
Faulkner	2,685	1,815	0	0	0
Greene	79,625	62,804	2,945	107	0
Independence	11,632	7,764	201	0	0
Jackson	76,208	68,299	16,670	1,066	1,672
Jefferson	59,832	55,438	697	0	4,447
Lafayette	2,676	3,164	0	0	316
Lawrence	96,131	83,775	11,676	0	17,940
Lee	18,372	16,540	161	63	1,702
Lincoln	18,441	12,104	193	0	10
Lonoke	77,697	68,474	2,290	307	0
Mississippi	34,093	27,261	295	0	1,476
Monroe	50,141	37,199	1,921	108	0
Phillips	16,140	18,177	231	0	0
Poinsett	106,696	86,445	30,118	3,251	947
Prairie	54,432	54,202	5,433	86	5,892
Pulaski	3,333	3,371	0	0	0
Randolph	34,028	29,145	5,838	0	1,683
St. Francis	30,283	26,454	2,290	0	27
White	12,348	9,885	896	0	0
Woodruff	53,219	47,389	1,410	0	5,185
Others[c]	6,370	5,927	40	0	233
Unaccounted[d]	39,407	14,808			
2013 Total		1,070,000	106,396	8,207	63,749
2013 Percent		100	9.94	0.77	5.96
2012 Total	1,280,000		93,719	14,546	50,309
2012 Percent	100		7.32	1.10	3.93

[a] Harvested acreage. Source: USDA, NASS, 2014.

[b] Other varieties: Antonio, CL131, CL142-AR, CL161, CL261, Caffey, Cheniere, Cocodrie, Colorado, Della-2, Dellrose, Francis, Jazzman, Jazzman-2, Mermentau, Rex, RiceTec CLXL746, RiceTec CLXP4534, RiceTec XP4523, and Taggart.

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

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

[e] CL152 and RiceTec XL753 were not included in the enrollment for 2012 but likely accounted for some percentage of CL151 and RiceTec XL723, respectively.

harvested rice acreage summary

Long-grain								
CL151	CL152	CLXL729	CLXL745	XL723	XL753	Roy J	Wells	Others[b]
1,579	3,078	2,593	22,649	3,972	10,362	9,766	1,248	9,496
0	391	931	1,085	0	1,245	242	0	382
0	2,163	5,155	6,009	3	6,896	1,341	0	2,116
13,053	8,453	6,755	19,549	1,337	4,783	1,105	2,215	545
596	166	0	0	0	76	301	0	565
14,956	5,952	0	7,857	2,014	825	9,094	2,468	1,172
658	591	1,452	5,213	1,780	1,395	4,125	749	2,223
8,486	2,967	2,769	13,737	1,932	1,604	12,428	2,225	4,075
0	4,188	202	4,231	0	0	756	0	0
0	613	1,461	1,703	1	1,955	380	0	600
0	201	0	470	0	0	969	0	174
11,895	6,358	0	21,093	1,594	7,941	5,709	797	4,364
234	0	2,335	389	0	3,670	934	0	0
8,404	2,788	7,863	13,454	1,939	1,171	9,279	121	3,871
13,898	7,848	0	14,231	0	0	13,685	0	632
396	396	0	949	0	316	475	0	316
10,970	15,367	1,618	1,147	4,110	772	8,470	0	11,705
331	0	2,839	5,518	600	925	3,315	0	1,087
10	10	856	8,265	10	2,729	10	0	10
2,711	4,806	8,299	38,285	2,461	3,180	3,381	4	2,747
1,212	3,211	0	1,487	1,137	0	1,487	12,458	4,499
606	857	943	1,457	497	960	13,528	2,451	13,872
0	0	2,496	4,544	0	0	7,271	0	3,635
6,737	5,377	1,871	10,765	139	3,094	14,164	4,173	5,808
0	2,955	6,425	15,682	2,165	6,623	3,049	0	5,892
169	236	438	1,888	135	169	236	0	101
0	0	11,257	3,719	4,291	0	1,935	0	421
2,569	1,852	0	939	1,664	678	8,668	4,340	3,428
347	0	3,531	811	1,950	0	2,174	0	176
3,970	1,509	5,927	9,718	1,942	4,644	9,263	352	3,469
111	570	1,464	1,512	809	462	422	0	304
								14,808
103,897	82,903	79,479	238,356	36,484	66,474	147,961	33,601	98,762
9.71	7.75	7.43	22.28	3.41	6.21	13.83	3.14	9.58
161,963	0[e]	141,861	352,192	121,566	0[e]	78,665	75,682	189,240
12.65	0[e]	11.08	27.52	9.50	0[e]	6.15	5.91	14.78

Table 2. Acreage, grain yield, and production of rice in the United States from 2011 to 2013[a].

	Area planted			Area harvested			Yield			Production		
State	2011	2012	2013	2011	2012	2013	2011	2012	2013	2011	2012	2013
	------------------------------ (1,000 acres) ------------------------------						------------(lb/acre) -----------			--------- (1,000 cwt[b]) ---------		
AR	1,196	1,291	1,076	1,154	1,285	1,070	6,770	7,470	7,560	78,100	95,922	80,888
CA	585	562	566	580	557	561	8,350	8,100	8,480	48,402	45,137	47,574
LA	423	402	418	418	397	413	6,320	6,430	7,300	26,430	25,540	30,135
MS	160	130	125	157	129	124	6,850	7,200	7,400	10,755	9,288	9,176
MO	143	180	159	128	177	156	6,490	6,990	7,030	8,308	12,372	10,968
TX	182	135	145	180	134	144	7,190	8,370	7,740	12,946	11,217	11,145
US	2,689	2,700	2,489	2,617	2,679	2,468	7,067	7,449	7,694	184,941	199,546	189,886

[a] Source: USDA-NASS, 2014.

[b] cwt = hundredweight.

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

	2010[b]		2012		2013	
Cultural practice	Acreage	% of total	Acreage	% of total	Acreage	% of total
Arkansas rice acreage	1,785,000	100.00	1,285,000	100.00	1,070,000	100.00
Soil texture						
Clay	421,048	23.6	267,547	20.8	209,251	19.6
Clay loam	368,753	20.7	282,736	22.0	252,702	23.6
Silt loam	947,311	53.1	677,951	52.8	547,386	51.2
Sandy loam	43,478	2.4	47,819	3.7	45,733	4.3
Sand	3,530	0.2	8,945	0.7	14,928	1.4
Tillage practices						
Conventional	1,253,005	70.2	716,782	55.8	654,647	61.2
Stale seedbed	388,184	21.7	445,484	34.7	329,807	30.8
No-till	139,403	7.8	122,734	9.6	85,546	8.0
Crop rotations						
Soybean	1,267,226	71.0	916,297	71.3	759,792	71.0
Rice	373,008	20.9	311,366	24.2	225,690	21.1
Cotton	15,192	0.9	3,199	0.2	5,586	0.5
Corn	41,277	2.3	35,035	2.7	45,006	4.2
Grain sorghum	7,803	0.4	6,519	0.5	6,810	0.6
Wheat	3,439	0.2	1,798	0.1	13,107	1.2
Fallow	12,478	0.7	10,784	0.8	13,705	1.3
Other	0	0.0	0	0.0	305	0.0
Seeding methods						
Drill seeded	1,244,919	69.7	1,025,022	79.8	881,172	82.4
Broadcast seeded	487,386	27.3	259,988	20.2	183,112	17.1
Water seeded	92,064	5.2	65,984	5.1	32,570	3.0
Irrigation water sources						
Groundwater	1,395,155	78.2	987,160	76.8	848,435	79.3
Stream, rivers, etc.	181,883	10.2	165,619	12.9	109,822	10.3
Reservoirs	182,082	10.2	132,219	10.3	111,743	10.4
Irrigation methods						
Flood, levees	953,821	53.4	785,104	61.1	698,139	65.2
Flood, multiple inlet	804,524	45.1	495,357	38.5	368,092	34.4
Furrow	9,810	0.5	4,323	0.3	3,769	0.4
Sprinkler	1,340	0.1	214	0.0	0	0.0
Stubble management						
Burned	782,838	43.9	327,698	25.5	303,204	28.3
Tilled	898,870	50.4	494,574	38.5	430,519	40.2
Rolled	790,564	44.3	289,202	22.5	316,705	29.6
Winter flooded	265,562	14.9	231,624	18.0	203,971	19.1

continued

Table 3. Continued.

	2010[b]		2012		2013	
Cultural practice	Acreage	% of total	Acreage	% of total	Acreage	% of total
Land management						
Contour levees	838,815	47.0	432,724	33.7	345,944	32.3
Precision-level	822,441	46.1	719,358	56.0	603,039	56.4
Zero-grade	123,743	6.9	132,918	10.3	121,016	11.3
Precision agriculture						
Yield monitors	498,711	27.9	748,705	58.3	553,505	51.7
Grid sampling	189,995	10.6	311,706	24.3	240,490	22.5
Variable-rate fertilizer	161,817	9.1	287,254	22.4	202,822	19.0
Pest management						
Insecticide seed treatment	----	----	746,456	58.1	653,049	61.0
Fungicide (foliar) application)	949,735	53.2	593,723	46.2	578,201	54.0
Insecticide (foliar) application)	798,647	44.7	373,251	29.0	457,649	42.8

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

[b] Survey used to generate data contained in this table was not conducted in 2011.

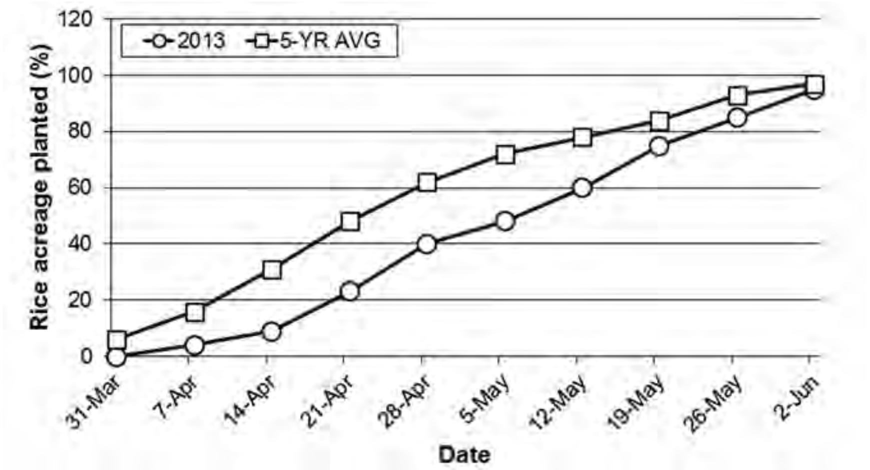

Fig. 1. Arkansas rice planting progress during 2013 compared to the five-year state average (NASS, 2014)

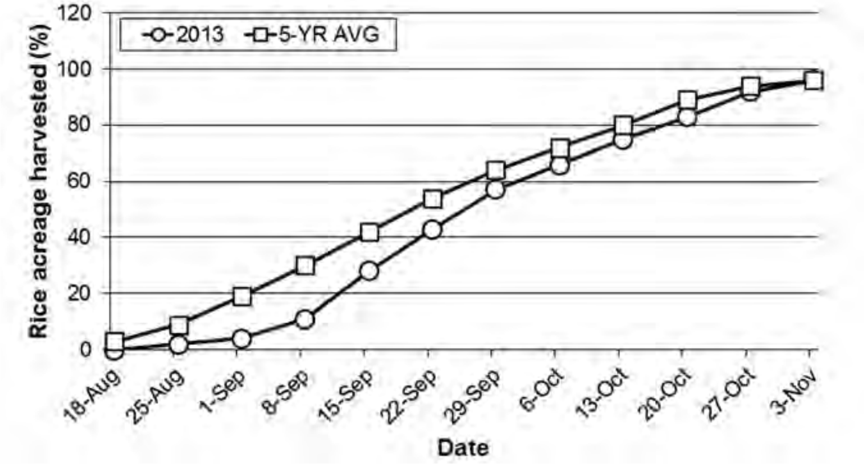

Fig. 2. Arkansas rice harvest progress during 2013 compared to the five-year state average (NASS, 2014)

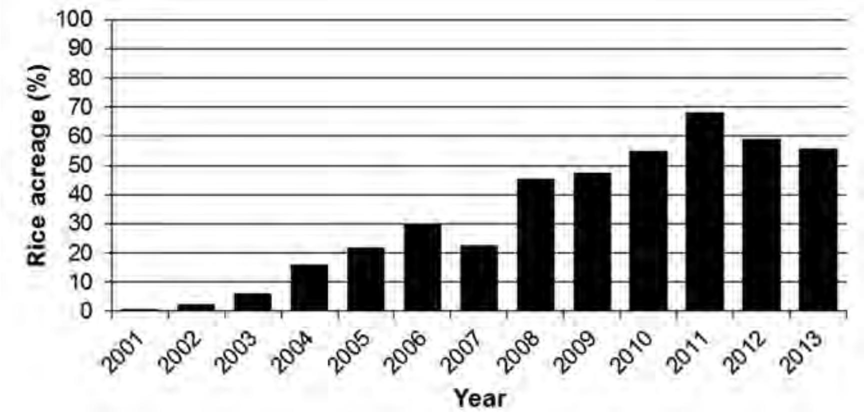

Fig. 3. Percentage of rice planted in Arkansas to Clearfield rice cultivars between 2001 and 2013.

2013 Rice Research Verification Program

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ABSTRACT

The 2013 Rice Research Verification Program (RRVP) was conducted on 21 commercial rice fields across Arkansas. Counties participating in the program included Arkansas (3 fields), Chicot (2 fields), Clark, Clay, Conway, Cross, Desha, Independence, Jackson, Jefferson, Lawrence, Lee, Lincoln, Phillips, Poinsett, Prairie, Randolph, White, and Yell Counties for a total of 1,192 acres. Grain yield in the 2013 RRVP averaged 192 bu/acre ranging from 140 to 249 bu/acre. The 2013 RRVP average yield of 192 bu/acre was 24 bu/acre greater than the estimated Arkansas state average of 168 bu/acre. The highest-yielding field was in Conway County with a grain yield of 249 bu/acre. The lowest yielding field was in Lawrence County which produced 140 bu/acre. Milling quality in the RRVP was comparable with milling from the Arkansas Rice Performance Trials and averaged 58/70 (i.e., 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 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 Cooperative Extension Service 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 Cooperative Extension Service educational programs at the county and state level. Since 1983, the RRVP has been conducted on 378 commercial rice fields in 33 rice-producing counties in Arkansas. The program has typically averaged about 20 bu/acre better than the state average yield. This increase in yield over the state average can mainly be attributed to intensive cultural management and integrated pest management.

PROCEDURES

The RRVP fields and cooperators are selected prior to the beginning of the growing season. Cooperators agree to pay production expenses, provide expense data, and implement Cooperative Extension Service recommendations in a timely manner from planting to harvest. A designated 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 were 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 Extension specialists and researchers with rice responsibility , assists in decision-making, development of recommendations, and program direction. Field inspections by committee members were utilized to assist in fine-tuning recommendations.

Counties participating in the program during 2013 included Arkansas (3 fields), Chicot (2 fields), Clark, Clay, Conway, Cross, Desha, Independence, Jackson, Jefferson, Lee, Lincoln, Phillips, Poinsett, Prairie, Randolph, White, and Yell Counties. The 22 rice fields totaled 1,192 acres enrolled in the program. Eight different cultivars were seeded (CL111, CL151, CL152, RiceTec CLXL745, Jupiter, Roy J, RiceTec XL753, and Francis) and Cooperative Extension Service recommendations were used to manage the RRVP fields. Agronomic and pest management decisions were based on field history, soil test results, cultivar, and data collected from individual fields during the growing season. An integrated pest management philosophy is utilized based on Cooperative Extension Service 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

Yield

The average RRVP yield was 192 bu/acre with a range of 140 to 249 bu/acre (Table 1). The RRVP average yield was 24 bu/acre more than the estimated state yield of 168 bu/acre. This difference has been observed many times since the program began and can be attributed in part to intensive management practices and utilization of Cooperative Extension Service recommendations. The Conway County field, seeded with RiceTec XL753, was the highest yielding RRVP field at 249 bu/acre. Nine of the 22 fields enrolled in the program exceeded 190 bu/acre. Lawrence County had the lowest yielding field with RiceTec XL753 producing 140 bu/acre.

Milling data was recorded on all of the RRVP fields. The average milling yield for the 22 fields was 58/70 (head rice/total white rice) with the highest milling yield of 64/71 occurring in the Lawrence County field of CL111 (Table 1). The lowest milling yield was 53/68 and occurred in the Prairie County field of Roy J. The milling yield of 55/70 is considered the standard used by the rice milling industry.

Planting and Emergence

Planting began with Arkansas County #2 on 20 April and ended with Clay County planted 20 May (Table 1). The majority of the verification fields were planted in May. An average of 81 lb seed/acre was planted for pureline varieties and 23 lb seed/acre for hybrids (Table 1). Seeding rates were determined with the Cooperative Extension Service RICESEED program for all fields. An average of 11 days was required for emergence. Stand density averaged 22 plants/square foot (ft^2) for pureline varieties and 8 plants/ft^2 for hybrids. The seeding rates in some fields were higher than average due to planting method, soil texture, and late planting dates. Broadcast seeding and clay soils require an elevated seeding rate.

Fertilization

N-ST*R (Nitrogen Soil Test for Rice) was utilized on all 22 RRVP fields. N-ST*R is calibrated based on soil texture and cultivar and can account for the previous crop credits and thus, the nitrogen fertilizer rate recommendations made with N-ST*R take into account all three of these factors (Table 2). Nitrogen rates can appear high in some fields where the cultivar requires more nitrogen than other cultivars, clay was the soil texture, and rice was the previous crop. These factors increase the nitrogen fertilizer requirements compared to a cultivar which requires a lower nitrogen fertilizer rate, silt loam was the soil texture, and soybean was the previous crop.

Ammonium sulfate (21-0-0-24) was applied in some fields at the 2- to 3-leaf stage as a management tool to increase plant growth and shorten the time required to get the rice to flood stage or to correct sulfur deficiencies (Table 2). Ammonium sulfate was applied at a rate of 75 to 100 lb/acre in Chicot #1, Desha, Independence, Jackson, and Phillips Counties.

Phosphorus (P), potassium (K), and zinc (Zn) were applied based on soil-test results (Table 2). Phosphorus and/or K and Zn were applied preplant in most of the fields. Phosphorus was applied to Arkansas #1, Arkansas #2, Arkansas #3, Clark, Clay, Independence, Lee, Lincoln, Phillips, Poinsett, Prairie, Randolph, and White County fields. In three counties (Arkansas #3, Lincoln, and Prairie), the P was in the form of diammonium phosphate (DAP; 18-46-0). Zinc was applied as a seed treatment in fields with hybrid rice at a rate of 0.5 lb Zn/60 lb/seed. The average cost of fertilizer across all fields was $149.28/acre (Table 3), which was $18.54/acre less than in 2012.

Weed Control

Command was utilized in 7 of the 22 fields for early-season grass control (Table 3). Facet was applied in 18 fields (Arkansas #1, Arkansas #2, Arkansas #3, Chicot #1, Chicot #2, Clay, Cross, Clark, Independence, Jackson, Jefferson, Lee, Lawrence, Lincoln, Phillips, Poinsett, Randolph, and Yell Counties) early post-emergence. Three fields (Conway, Desha, and Lee) utilized Facet as a herbicide for pre-emergence weed control. Nine fields (Arkansas #1, Arkansas #3, Chicot #1, Clark, Clay, Desha, Lawrence, Lincoln, and Randolph Counties) were seeded in Clearfield cultivars and Newpath and Clearpath were applied for control of red rice and other weeds. All of the fields required a post-emergence herbicide application for grass weed control.

Disease Control

Foliar fungicides were applied to eight of the 22 fields in 2013 for control of sheath blight and/or suppression of false smut and kernel smut (Table 4). Thirteen fields had a seed treatment containing a fungicide. Quilt Xcel, Tilt, or Stratego were used to control sheath blight and/or provide suppression of false smut and kernel smut. Fungicide rates were determined based on cultivar, growth stage, climate, disease incidence/severity, and disease history.

Insect Control

Two fields (Jefferson and White Counties) were treated with a foliar application for rice water weevil control in 2013 (Table 4). Nine fields (Arkansas #3, Chicot #2, Clay, Conway, Desha, Independence, Lee, Lincoln, and Prairie Counties) received a foliar insecticide application for rice stink bugs. Twelve fields (Chicot #1, Chicot #2, Clark, Clay, Conway, Desha, Jackson, Lawrence, Lee, Lincoln, Poinsett, and Randolph Counties) received an insecticide seed treatment in the form of CruiserMaxx Rice and two fields (Arkansas #1 and Arkansas #3) received NipsIt INSIDE insecticide seed treatment.

Irrigation

Well water was used to irrigate 13 of the 22 fields in the 2013 RRVP while 8 fields were irrigated with surface water. Three fields (Chicot #2, Conway, and Desha Counties) were zero-grade. Five fields (Arkansas #1 Clay, Lee, Prairie, and Randolph Counties) used multiple inlet (MI) irrigation either by utilizing irrigation tubing or by having multiple risers or water sources (Table 5). Flow meters were used in eight of the fields to record water usage throughout the growing season. In fields where flow meters were not utilized, the typical 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 3.90 inches to 22.60 inches. Typically, a 25% reduction in water use is observed when using MI irrigation.

Economic Analysis

This section provides information on production costs and returns for the 2013 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 22 fields were applied to determine costs and returns above operating costs, as well as total specified costs. Operating costs and total costs per bushel indicate the commodity price needed to meet each cost type.

Operating costs are those expenditures that would generally require annual cash outlays and would be included on an annual operating loan application. Actual quantities of all operating inputs as reported by the cooperators are used in this analysis. Input prices are determined by data from the 2013 Crop Enterprise Budgets published by the Cooperative Extension Service and information provided by the cooperating producers. Fuel and repair costs for machinery are calculated using a budget calculator based on parameters and standards established by the American Society of Agricultural and Biological Engineers. Machinery repair costs should be regarded as estimated values for full-service repairs and actual cash outlays could differ as producers provide unpaid labor for equipment maintenance.

Fixed costs of machinery are determined by a capital recovery method which determines the amount of money that should be set aside each year to replace the value of equipment used in production. Machinery costs are estimated by applying engineering formulas to representative prices of new equipment. This measure differs from typical depreciation methods as well as actual annual cash expenses for machinery.

Operating costs, fixed costs, costs per bushel, and returns above operating and total specified costs are presented in Table 6. Costs in this report do not include land costs, management, or other expenses and fees not associated with production. Operating costs per acre ranged from $453.49/acre for Jefferson County to $842.87/acre for Lawrence County, while operating costs per bushel range from $2.26/bu for Arkansas County #3 to $6.02/bu for Lawrence County. Total costs per acre (operating plus fixed) ranged from $519.97/acre for Jefferson County to $943.53/acre for Lawrence County, and total costs per bushel ranged from $2.71/bu for Arkansas County #3 to $6.74/bu for Lawrence County. Returns above operating costs ranged from $77.30/acre for Lawrence County to $964.97/acre for Arkansas County #3, and returns above total costs ranged from -$23.36/acre for Lawrence County to $868.30/acre for Arkansas County #3.

A summary of yield, rice price, revenues, and expenses by type for each RRVP field is presented in Table 7. The average rice yield for the 2013 RRVP was 192 bu/acre but ranged from 140 bu/acre for Lawrence County to 249 bu/acre for Conway County. The Arkansas average long-grain cash price for the 2013 RRVP was estimated from August 1 through October 31 daily price quotes to be $6.43/bu. The RRVP had one field planted to a medium-grain cultivar (Poinsett County). The average medium-grain price contracted in Arkansas was estimated to be $6.41/bu and represented the average long-grain price plus an average medium-grain discount of -$0.011/bu. The average medium-grain discount was estimated based on the average difference in Arkansas milled rice value between medium- and long-grain rice obtained from the Arkansas Weekly

Grain Review for the period August 9 through October 25, converted to a rough rice equivalent. A premium or discount was given to each field based on the milling yield observed for each field and standard milling yields of 55/70 for long-grain rice and 58/69 for medium-grain rice. Broken rice was assumed to have 60% 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 $6.12/bu in Lincoln County to $6.74/bu in Arkansas County #2. The medium-grain price adjusted for milling yield for Poinsett County (the one RRVP field growing medium-grain rice) was $6.60/bu.

The average operating expense for the 22 RRVP fields was $627.65/acre (Table 7). Fertilizers and nutrients accounted for the largest share of operating expenses on average (23.8%) followed by post-harvest expenses (17.8%), chemicals (15.5%), seed (12.4%), and irrigation energy costs (9.7%). Although seed cost accounted for 12.4% of operating expenses across the 22 fields, it's average cost and share of operating expenses varied depending on whether a Clearfield hybrid was used ($158.09/acre; 22.8% of operating expenses), a non-Clearfield hybrid was used ($126.72/acre; 19.7% of operating expenses), a Clearfield non-hybrid (pureline) variety was used ($72.40/acre; 11.6% of operating expenses) or a non-Clearfield non-hybrid (pureline) variety was used ($35.31/acre; 5.9% of operating expenses).

The average return above operating expenses for the 22 fields was $612.09/acre and ranged from $77.30/acre for Lawrence County to $964.97/acre for Arkansas County #3 (Table 6). The average return above total specified expenses for the 22 fields was $525.84/acre and ranged from -$23.36/acre for Lawrence County to $868.30/acre for Arkansas County #3. Table 8 provides select variable input costs for each field and includes a further breakdown of chemical costs into herbicides, insecticides, and fungicides as well as the specific rice cultivars grown on each RRVP field.

DISCUSSION

Field Summaries

Northern Counties

The precision-graded Clay County field was located southeast of Datto on a Crowley silt loam soil. The field was 29 acres and the previous crop was soybean. In March, conventional tillage practices were used for field preparation and a preplant fertilizer based on soil test analysis was applied at a rate of 0-40-60 (N-P_2O_5-K_2O) lbs/acre. On 20 May, RiceTec CLXL745 with the company's standard seed treatment was drill-seeded at a rate of 23 lb/acre. Rice emergence was observed on 27 May and consisted of 8 plants/ft^2. Clearpath and Command herbicides were tank-mixed and applied early post-emergence to the field, providing good pre- and post-emergence control of weeds. Using the N-ST*R recommendation, pre-flood urea + NBPT was applied at a rate of 210 lb/acre on 23 June. Due to the extended time (>10 days) needed to establish the permanent flood on the lower portion of the field, the lower 8 acres of the field had an additional 100 lb/acre of urea applied prior to flooding to supplement any nitrogen loss that could have potentially occurred. Once the permanent flood was established, flood levels were maintained well throughout the season. Prior to midseason, red rice and amazon sprangletop escapes were controlled with Beyond herbicide. Rain and cloudy weather were prevalent in August and the field received more than 12 inches of rain during this time which aggravated the sheath blight fungus. However, treatment thresholds were not met and fungicide applications were not required. On 6 August, the boot application of 70 lb/acre of urea was applied. At rice heading, rice stink bug populations were at threshold levels and effectively controlled with a single application of Lambda Cy insecticide. Total rainfall for the season was 16.7 inches. Harvest began 13 October and the dry yield for the field was 175 bu/acre. This yield was above average for other fields in the area with this planting window and had to endure cloudy and rainy conditions during pollination. The milling yield was 60/70.

The zero-graded Conway County field was 52 acres and located southwest of Morrilton on a Dardanelle silt loam soil. This was the second year in a row for this field to be in the RRVP. Conventional tillage was utilized on the field in late winter to early spring. Prior to planting, fertilizer was applied at a rate of 0-0-60 lb/acre due to the field being in a rice-only rotation. RiceTec XL753 with the company's standard seed treatment was drill-seeded on 11 May at a rate of 23 lb/acre. Rice emergence was observed on 20 May and consisted of 8 plants/ft^2. Seedbed conditions at planting were cloddy and very rough which hampered rice emergence and caused variability in growth stages. On 18 May, a pre-emergence application of Facet, Permit, and Command was used for broadleaf and grass control following planting. The field was flushed shortly after to activate the herbicides and to improve stand density. On 19 June, the field received 305 lb/acre of urea + NBPT based on the N-ST*R recommendation as a single pre-flood application and the permanent flood was started. A post-flood Clincher herbicide application was necessary for control of amazon sprangletop and barnyardgrass escaping the pre-emergence application. The field held a deep flood throughout the entire season following permanent flood establishment. Low disease incidence was observed in the field and no fungicide applications were recommended. Once rice reached the heading stage, the field was scouted for rice stink bugs. Populations were at 3X threshold levels at early heading and effectively controlled by a single application of Lambda Cy insecticide. Very sporadic heading was observed in the field due to the presence of volunteer rice and variable rice emergence due to the cloddy seed-bed conditions. Total rainfall for the season was 8.2 inches. Harvest began 7 October and the field yielded a new RRVP record 249 dry bu/acre. This was 38 bu/acre better than last year. The milling yield for the field was 54/70.

The precision-graded field in Cross County was 82 acres and located east of Crowley's Ridge south of the community of Coldwater on an Earl clay soil. The field was in soybean production the previous year. Following conventional tillage in early May, the field was drill-seeded on 15 May with 91 lb/acre of Francis seed-treated with Apron and Maxim fungicides. For pre-emergence grass control, Command was applied soon after planting. Measurable rainfall fell within a week of planting and activated the Command and helped with stand establishment. Rice emergence occurred on 26 May and consisted of an average of 30 plants/ft^2. The rice progressed well after emergence. Facet, Grandstand, and Aim were applied at the pre-flood timing for moderate patches of barnyardgrass and widespread black-seeded broadleaf weeds. Pre-flood urea + NBPT was applied on 22 June based on the N-ST*R recommendation at a rate of 220 lb/acre. After establishing the flood, barnyardgrass patches were observed that were not exhibiting Facet symptomology and Clincher was recommended for control. Facet was used instead and resulted in little if any activity. At the midseason timing, 100 lb/acre of urea was applied on 14 July. An adequate flood depth was maintained throughout the season. Sheath blight and rice stink bugs were present during the season, but never reached action threshold levels. Herbicide drift was observed during the late-boot stage and glufosinate was suspected based on the symptomology. The field was pumped up at 100% heading at which time it was recommended to turn the well off for the year due to the clay soil type. The field was eventually drained on 13 September and harvest started on 9 October. Total rainfall for the growing season was 19.2 inches. The field yielded 182 bu/acre and the producer was pleased with the yield considering the planting date and the weather experienced in August. The milling yield for the field was 62/69.

The 51-acre, precision-graded field in eastern Independence County was located near Oil Trough on an Egam silt loam soil. Soybean was planted in the field the previous year. Prior to planting, fertilizer at 0-50-90 lb/acre was applied based on soil test analysis. Conventional tillage practices were used to prepare the field for planting. On 22 April, Roy J rice seed, treated with Apron, Maxim, and Release, was drill-seeded at a rate of 80 lb/acre. Soon after planting, Command was applied pre-emergence for grass control. The rice emerged to a stand of 26 plants/ft^2 on 6 May. At the three-leaf rice stage, 100 lb/acre of ammonium sulfate was applied to increase the vigor and combat plant health issues resulting from the combination of Command and cool and wet conditions. Rice plants responded well to the application. Consistent rainfall at the pre-flood timing (3 June) delayed the urea application. Meanwhile, grass escapes were noticed in the field and an application of Stam M-4 and Prowl was made. Pre-flood urea + NBPT was eventually applied on 13 June at the N-ST*R recommended rate of 150 lb/acre and the permanent flood was established in 48 hours using the MI rice irrigation method. The producer said this was half the time it usually took to establish the flood on the field and the first time he had used the MI irrigation method. The producer indicated that he would continue the practice on all his fields next year. At midseason, the N-ST*R recommendation was to omit additional urea, but due to the late pre-flood application and the current plant health an additional 100 lb/acre of urea was applied on 9 July. At the mid-boot stage, Tilt fungicide was applied as a preventative for kernel and false smut due to the susceptibility of Roy J and a field history of these diseases. At heading, the field was scouted for rice stink bugs and threshold levels (Average >5 per 10 sweeps) were observed prompting an application of Lamda Cy for their control. Flood levels were well maintained throughout the growing season using the MI irrigation method. Total rainfall for the growing season was 18.4 inches. The field was drained on 2 September and harvest commenced on 20 September following an application of sodium chlorate for foliage desiccation. The field averaged 193 bu/acre and according to the producer significantly surpassed the previous highest yield produced on the field. Milling yield was a 59/71.

The precision-graded 36-acre Jackson County field was located west of Tuckerman on a Bosket fine sandy loam. The field was in the RRVP last year and this year was the third rice crop in a row produced there. Conventional tillage practices were utilized in late spring and 0-0-60 lb/acre fertilizer application was made prior to planting. Roy J treated with CruiserMaxx Rice was planted on 2 May at a rate of 72 lb/acre. Emergence was documented on 14 May with an average stand density of 26 plants/ft^2. An early post-emergence application of Facet and Riceshot was made for grass and broadleaf weed control 10 days following rice emergence. No additional weed control measures were needed for the remainder of the season. Urea + NBPT was applied preflood at 220 lb/acre based on N-ST*R recommendations and initiation of permanent flood began on 16 June. After the permanent flood was established, it was observed that the field sustained a drift application of glyphosate across the entire field. The field was then drained and fertilized with 100 lb/acre of ammonium sulfate to stimulate growth and vigor following the drift event. It was estimated that the event delayed the maturity by 7 to 10 days. At the mid-season timing (13 July), a single application of urea was applied at 100 lb/acre. Low disease and insect pressure were observed throughout the year and treatment was not advised. The field was drained 14 September and harvest began 2 October. The field yielded 149 bu/acre. This yield was 22 bu less than last year and probably due to the drift event that occurred. The milling yield was a 58/72.

The 86-acre Lawrence County field was located northwest of Light on a Foley-Calhoun Complex silt loam soil. Rice was the previous crop grown on the field. Conventional tillage practices were utilized in early spring and a 0-28-58 lb/acre fertilizer blend was applied prior to planting according to the soil-test recommendation. Clearfield 111 treated with CruiserMaxx Rice was planted at 86 lb/acre on 18 May and emerged to an average density of 16 plants/ft on 25 May. Pre-emergence herbicides could not be applied to the field due to excessive wind and rain, therefore Clearpath was applied early post-emergence on 5 June. Clearpath provided good activity on the barnyardgrass and 10 days later Newpath was applied to complete the control of emerged barnyardgrass and provide further residual activity. On 15 June, the N-ST*R recommended rate of 250 lb/acre of urea + NBPT was applied pre-flood and the permanent flood was initiated soon after using the MI rice irrigation method. Following permanent flood establishment, barnyardgrass was observed in several patches throughout the field and appeared to not be controlled by the Newpath application. Beyond was recommended as a post-flood application and provided no herbicide activity on the barnyardgrass. Due to the low performance of both Newpath and Beyond herbicides, it is possible these populations of barnyardgrass possess resistance to this family of herbicides and seed will be tested this winter for herbicide resistance. The producer has farmed this field for only a few years and used Clearfield technology once, but had no history on the previous year's production practices which could have included extensive selection pressure from multiple years of use of this family of herbicides. A second post-flood application including Clincher and Facet provided partial control of the barnyardgrass. At midseason, 100 lb/acre of urea was applied on 6 July. Quilt Xcel was applied at late boot for severe sheath blight pressure while also providing kernel and false smut prevention. The field was scouted weekly for rice stink bug populations, but threshold numbers were never detected. The field's rainfall total during the growing season was 17.3 inches. The field was drained on 19 September and harvest began 8 October following an application of sodium chlorate for foliage desiccation. The field yielded 140 bu/acre. Season-long barnyardgrass competition in portions of the field likely caused some yield reduction, but the milling yield was a respectable 64/71.

The 142-acre Poinsett County field was located in the north-central portion of the county on a Henry silt loam soil. Soybean was the previous crop grown on the field and conventional tillage practices were used for field preparation in early spring. Based on soil-test recommendations, a 0-45-60 lb/acre fertilizer blend was applied prior to planting. Jupiter treated with CruiserMaxx Rice and zinc was drill-seeded on 22 April at a rate of 78 lb/acre. Command herbicide was applied pre-emergence 2 days after planting for grass control. Rice emerged to a uniform stand density of 24 plants/ft^2 on 8 May. Command controlled weeds for approximately 3.5 weeks; but due to windy and rainy conditions experienced for 2 weeks, applicators could not treat the field timely with subsequent herbicide applications. A herbicide mixture of Facet, Regiment, and Permit Plus was eventually applied to large weeds on 5 June. Following the late post-emergence application, rainy and windy conditions again prevailed and preflood nitrogen was delayed another week. The N-ST*R recommended pre-flood application of urea + NBPT was finally applied on 12 June at 260 lb/acre. Permanent flood establishment began the following day and utilized the MI rice irrigation method designed by the Poinsett county agent. The MI method reduced the flood establishment time from what had typically been 8 days to only 4 days and kept the flood maintained well throughout the growing season. It should be noted that the 142-acre field contained a steep contour grade that fell several different directions which is typically difficult to water. On 3 July, mid-season urea was applied. Barnyardgrass escapes were observed after the midseason urea application, but due to the sparse density and timing, herbicide was not applied. Disease and insect levels remained below threshold levels all season and no fungicide or insecticide applications were made. Water pumped from a local reservoir maintained the flood on the field for the duration of the season until pumping ceased on 2 September and the field was drained 8 days later. Rainfall during the growing season totaled 22.6 inches. Harvest began on 19 October and the field yielded 188 bu/acre with a milling yield of 62/70. The producer was very pleased with the yield considering the environmental issues that were experienced during the growing season.

The zero-grade Prairie County field was 36 acres located southeast of Biscoe on a Sharkey Clay soil. The previous crop grown on the field was soybean. No tillage practices were performed on the field following the previous soybean crop. Untreated Roy J seed was water-seeded into a 1-inch flood on 22 April at a rate of 115 lb/acre. Emergence was observed 10 days later when the rice pegged down and consisted of 26 plants/ft. After pegging, a very shallow flood was established and the water level was brought up as the rice height increased. Flooding from the adjacent Cache River complicated flood maintenance during the early rice growth. At the mid post-emergence stage (3- to 4-lf rice), a tankmix of Duet, Stam M-4, and Londax was applied for control of grass and aquatic broadleaf weeds. On 31 May at the tillering stage, 100 lb/acre of urea was applied and 12 days later, 100 lb/acre of urea and 100 lb/acre of DAP were applied. Diammonium phosphate was added based on soil-test recommendations for phosphorus fertilization. Another 100 lb/acre of urea was applied 20 June to complete the nitrogen fertility program on the field. Clincher herbicide was applied on 12 June to control fall panicum populations in the field. No significant disease issues were observed in the field and no fungicide applications were warranted. Rice stink bug populations at 75% heading were above threshold levels and were treated with Karate insecticide. The rainfall total for the growing season was 15.8 inches. The field was drained 19 August and harvest started on 10 September. The field yielded 185 bu/acre and milled 53/67. The producer was expecting 160 bu/acre and thus, he was very happy with the performance.

The precision-graded, 30-acre field in Randolph County was located northeast of Pocahontas near the community of Engelberg on a Hontus silt loam soil. The previous crop grown on the field was rice. Conventional tillage practices were utilized and 0-60-90 lb/acre of fertilizer was applied prior to planting according to soil-test recommendations. The field was planted on 13 May with 24 lb/acre of RiceTec CLXL745 seed treated with the company's standard seed treatment. Emergence was observed on 28 May and consisted of 7 plants/ft^2. A week following emergence the field was flooded for 4 days with water backing up from the Current and Black Rivers. After the flood waters receded, the rice was slightly stretched, but improved within a week. The N-ST*R recommended preflood nitrogen was supplied as a 41-0-0-4S + NBPT at a rate of 300 lb/acre on 17 June. On the next day, a tankmix of Facet, Newpath, and RiceShot was applied for grass, red rice, and hemp sesbania control. Permanent flood establishment started eight hours following the preflood herbicide application. Beyond herbicide was applied at the green-ring stage (17 July) for control of red rice escaping the earlier Newpath application. Red rice control was good, but suspected Clearfield tolerant weedy rice populations remained in patches throughout the field. The boot application of urea was applied on 1 August at 70 lb/acre. Sheath blight was very aggressive after several weeks of rainy and cloudy conditions and had to be treated with Quadris fungicide at 25% heading. Total rainfall during the growing season was 17.3 inches. On 10 September, the field was drained. Defol 5 (sodium chlorate) was applied as a foliage desiccant on 30 September and harvest began one week later. The field yielded 171 bu/acre with a milling yield of 55/69.

The 27-acre White County field was situated in the northern portion of the county near Russell on a Callaway silt loam soil. Soybean was planted previously on the field. Conventional tillage methods were utilized in early spring and a fertilizer blend of 0-40-60 lb/acre was applied preplant in accordance with soil-test recommendations. Roy J seed, treated with Release, was drill-seeded on 24 April directly followed by a tankmix application of Command and Roundup WeatherMax herbicides for pre- and post-emergence annual grass and broadleaf control. Rice emerged to a stand averaging 24 plants/ft^2 on 10 May. Grass and yellow nutsedge were present at the preflood timing (5 June) and were controlled with Stam M-4, Bolero, and Permit. On the same day, the N-ST*R recommended rate of 220 lb/acre of urea + NBPT was applied. The permanent flood was initiated a day after the preflood urea application. Shortly after permanent flood establishment, rice water weevil pressure intensified and an application of Mustang Max was made to effectively control the populations. Mid-season urea at 100 lb/acre was applied on 6 July. Tilt fungicide was applied at the mid-boot timing for kernel and false smut prevention. Rice stink bug pressure stayed below threshold levels during the heading stage. The field was drained on 9 September. The total rainfall during the growing season was 20.6 inches. The field yielded 174 bu/acre and milled a 57/71. The producer acknowledged this was the best rice he had ever harvested and learned a lot from the experience.

The 34-acre Yell County field was located southeast of Dardanelle on a Roellen silty clay soil. The previous crop planted on the field was soybean and conventional tillage methods were performed in early spring. Roy J, seed-treated with Apron and Maxim, was drill-seeded at 82 lb/acre on 15 May. Three days later, a pre-emergence treatment of Obey herbicide was applied for broad-spectrum weed control. Stand emergence of 29 plants/ft^2 was noted on 1 June. A large field-wide flush of palmer amaranth emerged a few weeks after rice emergence and was controlled with a tankmix of Broadhead and Stam M-4 applied to early-tillering rice on 18 June. Preflood urea + NBPT was applied according to the N-ST*R recommendation of 250 lb/acre to the northern half of the field on 24 June. The aerial applicator couldn't finish the field that day because of personal issues. Five days passed before the application could be completed on the southern half of the field. The permanent flood was established in 3 days starting on 29 June. Mid-season urea was applied at rate of 100 lb/acre on 27 July. On 16 August, Quilt Xcel fungicide was applied to boot-stage rice for sheath blight control as well as kernel and false smut prevention. The field was drained on 2 October. During the growing season, the field received a total of 13.8 inches of rainfall. Harvest began 13 October and resulted in an average yield of 180 bu/acre. The milling yield was 53/69 and the average moisture was 15%.

Southern Counties

The precision-graded, 74-acre Arkansas County #1 field was located east of Stuttgart on a Dewitt silt loam soil and the previous crop was soybean. Conventional tillage practices were used for field preparation and a preplant fertilizer based on the soil test was applied at a rate of 0-60-90-10 ($N-P_2O_5-K_2O-Zn$) lb/acre. RiceTec CLXL745 was drill-seeded on 22 April at 20 lb/acre. NipsIt INSIDE insecticide seed treatment was used in addition to the company's standard seed treatment. Ammonium sulfate was used as a starter fertilizer at a rate of 100 lb/acre applied 5 May. The rice emerged on 6 May with a stand density of 6 plants/ft^2. Newpath herbicide was applied pre-emergence. Due to extended high wind issues (>20 days) the post-emergence herbicide application was delayed. Clearpath was applied 11 June as a post-emergence herbicide and provided adequate weed control. Permit Plus was applied 29 June and provided sufficient control of barnyardgrass and dayflower. Using the N-ST*R recommendation, preflood urea + NBPT was applied at a rate of 130 lb/acre on 12 June. Multiple inlet irrigation was utilized for the field ensuring a more efficient permanent flood. On 15 July, the urea was applied at late-boot at 70 lb/acre. The field was clean throughout the year and a deep flood was maintained. Irrigation amounts were 22 acre-inches with rainfall amounts totaling 3.9 inches. No fungicides were needed for disease control and no rice stink bug applications were warranted. The field was harvested on 4 September and yielded 219 bu/acre and was 20 bushels better than the grower's 2012 RRVP yield. The average harvest moisture was 18% and the milling yield was 58/72. This was the third-highest yield this year in the RRVP.

The 137-acre Arkansas County #2 field was located just northeast of Reydell on a Dewitt silt loam soil. The previous crop grown on the field was corn and conventional tillage practices were used to prepare the field for planting. Apron XL and zinc were used as seed treatments. Based on soil test recommendations, a preplant fertilizer blend of 0-60-120-10 ($N-P_2O_5-K_2O-Zn$) lb/acre was applied. On 20 April, the field was drill-seeded in Roy J at a rate of 67 lb/acre. The rice emerged on 13 May with a stand density of 15 plants/ft^2. Command and League herbicides were applied pre-emergence on 30 April followed by Superwham, Facet, and League applied post-emergence on 29 May. Due to extensive spring rains the pre-emergence herbicides remained activated giving season-long control of both grasses and broadleaves. Preflood nitrogen as urea was applied according to N-ST*R recommendations at 200 lb/acre pre-flood on 5 June, followed by 100 lb/acre urea at midseason. The irrigation source was surface water which provided a deep flood throughout the growing season. Rice stink bugs were sporadic early but never reached threshold levels. Quilt Xcel fungicide was applied 30 July for sheath blight control and prevention of kernel smut. Total rainfall for the season was 8.9 inches. The field was harvested on 25 September and yielded 215 bu/acre with a milling yield of 58/71. This is the second year the grower was well pleased with the cultivar, yield, and RRVP recommendations.

The precision-graded, 37-acre Arkansas County #3 field was located just south of Gillette on a Stuttgart silt loam soil. Soybean was planted in the field the previous year and conventional tillage practices were used to prepare the field. Prior to planting, pre-plant fertilizer at 0-18-36 lb/acre was applied based on soil-test recommendations. On 29 April, CL151 treated with NipsIt INSIDE was drill-seeded at a rate of 74 lb/acre. Command herbicide was applied at planting as a pre-emergence herbicide. The rice emerged on 8 May with a very uniform stand and the stand densities averaged 15 plants/ft^2. Clearpath and Permit were tank mixed and applied as post-emergence herbicides. Due to a very clean field and early-season persistent rain patterns, the field was brought to flood early at the 4-leaf stage. A shallow flood was maintained early then a deep flood was maintained the rest of the season. According to N-ST*R recommendations, 215 lb/acre urea was applied at pre-flood followed by 100 lb/acre at mid-season. At the second week of heading, the field was scouted for rice stink bug and threshold levels were reached (>10 rice stink bugs per 10 sweeps) prompting an application of Karate Z insecticide. After intense scouting, no late-season diseases were detected. Irrigation totaled 26.1 inches with 6.1 inches of rainfall. The field was harvested on 26 August with a yield of 218 bu/acre. The milling yield was 64/70 with an average moisture of 19%. The 2013 yield was 38 bu/acre better than the 2012 RRVP field.

The no-till, precision-graded 26-acre Chicot County #1 field was located northeast of Lake Village on a Sharkey clay soil. The previous crop grown on the field was corn. Prior to corn, the field was fallow in pasture for 50 years and then precision-graded. On 12 May, CL152, treated with CruiserMaxx Rice and zinc, was planted at 57 lb/acre. Newpath was applied on 15 May as a pre-emergence herbicide. Field emergence was recorded on 20 May with a stand density of 20 plants/ft^2. Ammonium sulfate was applied 30 May as a starter fertilizer. On 6 June, Command, Clearpath, and League were applied as post-emergence herbicides. An adequate flood was maintained throughout the year. Based on N-ST*R recommendations, nitrogen was applied as urea pre-flood at 200 lb/acre on 5 July with no mid-season application recommended. Rice stink bugs were scattered throughout the field but never reached treatment threshold levels. Rainfall amounts were 8.05 inches for the season. Tilt fungicide was applied for kernel smut prevention. The field was harvested 26 August with a yield of 191 bu/acre and milling yield of 62/68. The harvest moisture averaged 15%. Kernel smut was prevalent throughout the field but more severe in the fill areas.

The precision-graded, 45-acre Chicot County #2 field was located just north of Eudora on a Sharkey clay soil. The previous crop was soybean. The field had just been leveled and no tillage practices were performed prior to planting. The field was drill-seeded 23 April with Roy J at 80 lb/acre. The seed was treated with CruiserMaxx Rice seed treatment. Roundup and Aim herbicides were applied at planting as a burndown for existing vegetation. Emergence was observed on 2 May with a stand of 18 plants/ft^2. Command and League herbicides were applied post-emergence on 6 May. Barnyardgrass was very persistent each week. On 13 May, Propanil and Facet herbicides were applied followed by Superwham and Facet on 30 May. Due to recent field leveling, the southern part of the field was more mature than the northern part. On 1 June, urea was applied at 215 lb/acre according to N-ST*R recommendations. On 23 June, midseason nitrogen was applied as urea at 100 lb/acre. Rice stink bugs reached treatment threshold levels first on the south end and later on the north end of the field. Karate Z insecticide was applied 29 July and 8 August on the south and north sections of the field, respectively. Season rainfall amounts were 16.8 inches. The field was harvested 12 September and yielded 186 bu/acre. The milling yield was 58/70 and the harvest moisture averaged 19%.

The zero-grade, 40-acre Clark County field was located northwest of Arkadelphia on the Ouachita River on a Gurdon silt loam soil. The field had been fallow and recently leveled with conventional tillage practices utilized in the spring. On 2 May, RiceTec standard-treated CLXL745 was drill-seeded at 24 lb/acre. A 0-0-60 lb/acre pre-plant fertilizer was applied according to soil-test recommendations. Prowl H_20 was applied as a pre-emergence herbicide. Emergence was observed on 17 May averaging 9 plants/ft^2. On 30 May, Clearpath and Facet herbicides were applied post-emergence followed by Newpath and propanil on 21 June. There was an extended time to flooding (<21 days) due to pump issues. Chicken litter was applied at 2 tons/acre on 22 June. N-ST*R recommended urea at 250 lb/acre was applied 22 June. Boot fertilizer was applied as urea at 100 lb/acre on 8 August. The field was harvested late on 12 October with a yield of 200 bu/acre. The milling yield was 60/70 and the average moisture was 15%. The rainfall amount for the growing season was 8.2 inches.

The zero-grade, 48-acre Desha County field was located just southwest of McGehee on a Perry clay soil. No tillage practices were performed following the previous soybean crop. One ton of chicken litter was applied on 10 May. RiceTec CLXL745 was drill-seeded at a rate of 22 lb/acre on 13 May. The seed was treated with the company's standard seed treatment. Facet and Command herbicides were tank mixed as pre-emergence herbicides providing excellent weed control. Rice emergence was observed on 27 May with 8 plants/ft^2. A post-emergence application of Newpath and League herbicides was tank mixed and applied on 6 June for grass and aquatic weed control. A post-emergence application of Beyond herbicide was applied on 12 June. On 13 June, a single pre-flood application of urea was applied at 230 lb/acre according to N-ST*R recommendations. On 20 August, rice stink bugs reached treatment threshold levels and Karate Z insecticide was applied. The field was harvested 13 September and yielded 183 bu/acre with a milling yield of 54/68. The average harvest moisture was 15%. The irrigation amount was 17.5 inches and the rainfall amount was 5.3 inches.

The zero-grade, 67-acre, no-till Jefferson County field was located just off the Arkansas River between Pastoria and Altheimer on a Desha clay soil. The previous year half the field was soybeans and the other half was rice. Due to extreme rainfall in April, the field was water-seeded with Roy J at 90 lb/acre on 27 April. Emergence was recorded on 5 May with a stand density of 14 plants/ft^2. Regiment and Facet herbicides were applied post-emergence on 29 May and provided good control of grass, broadleaf, and aquatic weeds. Permit Plus was applied on 10 June for control of yellow nutsedge, flatsedge, and smartweed. Using the N-ST*R recommendation, urea + NBPT was applied at 300 lb/acre. Within 5 days after flood, adult rice water weevils were observed and scarring was prevalent throughout the field. On 24 June, an application of Belay insecticide was made and by the next week the field was clean. On 5 July, the midseason nitrogen fertilizer was applied as urea at 100 lb/acre. The flood was well maintained throughout the growing season. Irrigation amounts totaled 15.5 inches while rainfall totaled 4.7 inches. The field was harvested on 26 September with a yield of 186 bu/acre and a milling yield of 56/68. The average harvest moisture was 17%. The grower stated this is the second year he had good yields under adverse conditions.

The 39-acre Lee County field was located just east of Moro on a Loring silt loam soil. Soybean was the previous crop grown on the field. Conventional tillage practices were used for field preparation in early spring. A pre-plant fertilizer blend of 0-60-90-10-10 (N-P_20_5-K_20-Zn-S) lb/acre was applied in the spring according to soil-test recommendations. Glyphosate herbicide was used on 20 April as a burndown for existing vegetation. On 23 April, Roy J treated with CruiserMaxx Rice and zinc was drill-seeded at 75 lb/acre. Facet and Command were applied as pre-emergence herbicides on 26 April. An established stand was observed on 5 May averaging 22 plants/ft_2. Superwham, Facet, and Permit Plus herbicides were applied post-emergence. Based on N-ST*R recommendations, pre-flood urea + NBPT was applied at 210 lb/acre on 5 June. An adequate permanent flood was maintained throughout the growing season. There were grass escapes along the power lines of the south side of the field. A 20-acre load of Clincher plus methylated seed oil was applied on 24 June and provided fair control. Mid-season urea was applied on 1 July at 100 lb/acre. Rice stink bugs reached treatment threshold levels and on 5 August an application of Mustang Max insecticide was made. The field was harvested on 18 September yielding 226 bu/acre with a milling yield of 61/72 and an average harvest moisture of 16%. The season-long rainfall total was 10 inches. The grower was pleased with the yield and RRVP recommendations. This was the second-highest yield in the RRVP in 2013.

The precision-graded, 31-acre Lincoln County field was located near Fresno on a Perry clay soil. No tillage practices were performed following the previous crop of soybean. An 18-46-0 lb/acre pre-plant fertilizer was applied according to soil-test recommendations. In March, Roundup PowerMax and 2,4-D amine herbicides were used to control existing weedy vegetation. On 30 April, RiceTec standard seed-treated CLXL745 was drill-seeded at a rate of 28 lb/acre. Rice emergence was observed on 11 May and consisted of 8 plants/ft^2. Clearpath and Permit Plus herbicides were applied on 22 May to control heavy pressure from barnyardgrass, broadleaf signalgrass, and dayflower. On 3 June, Newpath herbicide was applied and the field remained clean throughout the season. Nitrogen as urea was applied pre-flood on 2 June at a rate of 350 lb/acre according to N-ST*R recommendations. An adequate flood level was maintained throughout the season. The late-boot nitrogen application was applied as urea on 16 July at 75 lb/acre. The field had a history of kernel smut and on 17 July Quilt Xcel fungicide was applied for suppression of this disease. Once rice reached the heading stage, the field was scouted for rice stink bug. Rice stink bug populations were at 3X threshold levels and were effectively controlled with a single application of Proaxis insecticide. The field was harvested on 9 September and yielded 217 bu/acre. The milling yield was 47/69 and the average harvest moisture was 16%. Rainfall total for the growing season was 6.65 inches.

The zero-graded, 43-acre Phillips County field was located south of Helena along the Mississippi River on a Sharkey silty clay soil. The previous crop grown on the field was rice. In the spring, Roundup WeatherMax was applied as a burndown for existing vegetation. Due to extensive spring rainfall on 13 May, Roy J rice seed, treated with Apron fungicide seed treatment, was water-seeded at 100 lb/acre. The rice emerged to a stand on 20 May with a stand density averaging 21 plants/ft^2. RicePro, Prowl, and Londax were applied as post-emergence herbicides for barnyardgrass, broadleaves, and aquatics. Based on soil-test recommendations, 18-46-0 lb/acre of fertilizer plus ammonium sulfate and zinc was applied on 28 May. On 5 June, another post-emergence herbicide application of Facet and Superwham was made. Preflood nitrogen as urea + NBPT was applied on 8 June at the N-ST*R recommended rate of 200 lb/acre. The permanent flood was established within 48 hours. Midseason fertilizer was applied as urea on 28 June at 100 lb/acre. The field was harvested on 26 September and yielded 186 bu/acre with a milling yield of 58/69. The average harvest moisture was 15% and the total rainfall was 7.75 inches.

SIGNIFICANCE OF FINDINGS

Data collected from the 2013 RRVP reflect the general trend of increasing rice yields and above average returns in the 2013 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.

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Table 1. Agronomic information for fields enrolled in the 2013 Rice Research Verification Program.

Field location by county	Cultivar	Field size	Previous crop	Seeding rate	Stand density	Planting date	Emergence date	Harvest date	Yield	Milling yield[a]	Harvest moisture
		(acres)		(lb/acre)	(plants/ft^2)			(bu/acre)		(%)	
Arkansas 1	RTCLXL745	74	Soybean	20	6	22 April	6 May	4 Sept	219	58/72	18
Arkansas 2	Roy J	137	Corn	74	15	20 April	13 May	25 Sept	215	58/71	15
Arkansas 3	CL151	37	Soybean	74	15	29 April	8 May	26 Aug	218	64/70	19
Chicot 1	CL152	26	Corn	57	20	12 May	20 May	26 Aug	191	62/68	15
Chicot 2	Roy J	45	Soybean	80	18	23 April	2 May	12 Sept	186	58/70	19
Clark	RTCLXL745	40	Fallow	24	9	2 May	17 May	12 Oct	200	60/70	16
Clay	RTCLXL745	29	Soybean	23	8	20 May	27 May	13 Oct	175	60/72	18
Conway	RTXL753	52	Rice	22	8	11 May	20 May	7 Oct	249	54/70	16
Cross	Francis	82	Soybean	91	30	15 May	26 May	9 Oct	182	62/69	19
Desha	RTCLXL745	48	Soybean	22	8	13 May	27 May	13 Sept	183	54/68	15
Independence	Roy J	51	Soybean	80	26	22 April	6 May	20 Sept	193	59/71	18
Jackson	Roy J	36	Rice	72	36	2 May	14 May	2 Oct	149	58/72	16
Jefferson	Roy J	67	Rice	90	14	27 April	5 May	26 Sept	186	56/68	17
Lawrence	CL111	86	Rice	80	16	18 May	25 May	8 Oct	140	64/71	15
Lee	Roy J	39	Soybean	75	22	23 April	5 May	18 Sept	226	61/72	16
Lincoln	RTCLXL745	31	Soybean	28	8	30 April	11 May	9 Sept	217	47/69	16
Phillips	Roy J	43	Rice	100	21	13 May	20 May	26 Sept	186	58/69	15
Poinsett	Jupiter	142	Soybean	78	24	22 April	8 May	19 Oct	188	62/70	16
Prairie	Roy J	36	Soybean	115	26	22 April	2 May	10 Sept	185	53/68	15
Randolph	RTCLXL745	30	Rice	24	7	13 May	28 May	7 Oct	171	55/69	15
White	Roy J	27	Soybean	70	24	24 April	10 May	2 Oct	174	57/71	16
Yell	Roy J	34	Soybean	82	29	15 May	1 June	13 Oct	180	53/69	15
Average	----	54	----	----[b]	----[c]	3 May	15 May	26 Sept	192	58/70	16

[a] Head rice milling yield / Total rice milling yield.

[b] Seeding rates averaged 81 lbs/acre for pureline varieties and 23 lb/acre for hybrids.

[c] Stand density averaged 22 plants/ft^2 for pureline varieties and 8 plants/ft^2 for hybrids.

Table 2. Soil test results, fertilization program, and soil classification for fields enrolled in the 2013 Rice Research Verification Program.

Field location by county	Soil test				Applied fertilizer			Soil classification
	pH	P[a]	K[a]	N[a]	Preplant[b] N-P-K-Zn-S[a]	Urea (45%N) rates applied by timing[c]	Total N rate[d]	
		(lb/acre)						
Arkansas 1	6.3	22	184	5.2	0-60-90-10	130-0-70	92	Dewitt Silt Loam
Arkansas 2	6.9	30	140	4.2	0-60-120-10	200-100-0	138	Dewitt Silt Loam
Arkansas 3	7.2	47	201	9.1	0-18-36-0-0	215-100-0	145	Dewitt Silt Loam
Chicot 1	5.4	64	660	7.4	24-0-0-0-21	200-0-0	103	Sharkey Clay
Chicot 2	6.1	54	628	8.3	0-0-0-0-0	215-100-0	145	Perry Clay
Clark	5.3	14	71	3.9	60-90-120-0-0[e]	250-0-75	177	Gurdon Silt Loam
Clay	6.0	37	221	4.1	0-40-60-1-0	210-0-70	129	Crowley Silt Loam
Conway	5.9	88	372	6.0	0-0-60-1-0	305-0-0	140	Dardanelle Silt Loam
Cross	6.5	54	286	6.0	0-0-0-1-0	220-100-0	147	Earle Clay
Desha	6.3	38	580	9.8	60-50-74-0-0[f]	230-0-0	133	Sharkey/Desha Clay
Independence	6.5	12	168	7.2	24-50-90-0-21	150-100-0	139	Egam Silt Loam
Jackson	6.0	80	195	2.4	24-0-60-10-21	220-100-0	171	Bosket Fine Sandy Loam
Jefferson	6.8	52	980	9.2	0-0-0-0-0	300-100-0	184	Perry Clay
Lawrence	7.0	38	122	8.7	0-60-120-1-0	250-100-0	161	Foley-Calhoun Complex Silt Loam
Lee	7.0	48	197	4.3	12-60-90-1-10	210-100-0	148	Foley-Bonn Complex
Lincoln	6.7	28	725	5.2	18-46-0-0-0	350-0-70	201	Perry Clay
Phillips	7.0	89	716	7.9	42-46-0-10-21	200-100-0	157	Foley Silt Loam
Poinsett	7.4	28	114	6.1	0-45-60-1-0	260-100-0	165	Henry Silt Loam
Prairie	6.0	36	276	4.6	18-46-0-0-0	200-100-0	156	Sharkey Soils Clay
Randolph	6.7	34	150	4.2	0-60-90-1-12	267-0-70	155	Hontus Silt Loam
White	5.7	38	198	5.2	0-40-60-0-0	220-100-0	147	Callaway Silt Loam
Yell	6.3	36	667	5.5	0-0-0-1-0	250-100-0	160	Roellen Silty Clay

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

[b] N-P_2O_5-K_2O-Zn-S (includes seed treatments and preplant applications).

[c] Timing: preflood - midseason - boot.

[d] All RRVP fields were fertilized according to N-ST*R recommendations.

[e] Analysis established from 1 ton/acre chicken litter.

[f] Analysis established from 1.5 tons/acre chicken litter and 100 lb/acre of potash fertilizer.

Table 3. Herbicide rates and timings for fields enrolled in the 2013 Rice Research Verification Program.

Field location by county	Pre-emergence herbicide applications	Post-emergence herbicide applications
	---------- (trade name & product rate/acre)[a] ----------	
Arkansas 1	Newpath (6 oz)	Clearpath (0.5 lb) fb Permit Plus (0.75 oz)
Arkansas 2	Command (12 oz) + League (3.2 oz)	Facet (0.5 lb) + League (3.2 oz) + Superwham (3 qt)
Arkansas 3	Command (13 oz)	Clearpath (0.5 lb) fb Permit (1 oz)
Chicot 1	Newpath (4 oz)	Command (11 oz) + Clearpath (0.5 lb) + League (6.4 oz)
Chicot 2	Glyphosate (32 oz) fb Command (11 oz) + League (3.2 oz)	Propanil (4 qt) + Facet (0.33 lb) fb Superwham (4 qt) + Facet (0.33 lb)
Clark	Prowl H2O (1.6 pt)	Clearpath (0.5 lb) + Facet (.10 lb) fb Newpath (4 oz) + Propanil (1 qt)
Clay	------[b]	Clearpath (0.5 lb) + Command (12 oz) fb Beyond (5 oz)
Conway	Command (12 oz) + Facet L (32 oz) + Permit (0.67 oz)	Clincher (15 oz)
Cross	Command (20 oz)	Facet (32 oz) + Grandstand (0.67 pt) + Aim (1 oz) fb Facet (11 oz)
Desha	Facet (0.5 lb) + Command (21 oz)	Newpath (5 oz) + League (6.4 oz) fb Beyond (5 oz)
Independence	Command (12 oz)	Stam M-4 (4 qt) + Prowl H2O (2 pt)
Jackson	------[b]	Facet (0.33 lb) + Riceshot (4 qt)
Jefferson	------[b]	Regiment (0.5 oz) + Facet (0.5 lb) fb Permit Plus (0.75 oz)
Lawrence	------[b]	Clearpath (0.5 lb) fb Newpath (6 oz) fb Beyond (6 oz) fb Facet L (16 oz) + Clincher (15 oz)
Lee	Glyphosate (32 oz) fb Facet (0.5 lb) + Command (11 oz)	Superwham (3 qt) + Facet (0.6 lb) + Permit Plus (0.75 oz)
Lincoln	Roundup (1 qt) + 2,4-D (1 qt)	Clearpath (0.5 lb) + Permit Plus (0.75 oz) fb Newpath (6 oz)
Phillips	Prowl (2.1 pt) + RicePro (4 qt)	Londax (1 oz) + Facet (0.4 lb) + Superwham (4 qt)
Poinsett	Command (12 oz)	Facet (32 oz) + Regiment (0.5 oz) + Permit Plus (0.75 oz)
Prairie	------[b]	Duet (4 qt) + Londax (0.25 oz) + Stam (1 qt) fb Clincher (15 oz)
Randolph	------[b]	Facet (32 oz) + Newpath (4 oz) + Riceshot (2 qt) fb Beyond (5 oz)
White	Roundup PowerMax (32 oz) + Command (16 oz)	RiceShot (4 qt) + Bolero (2 pt) + Permit (0.5 oz)
Yell	Obey (30 oz)	Broadhead (5 oz) + Stam (2 qt)

[a] The abbreviation fb stands for ‘followed by’ and is used to separate herbicide application events.

[b] Field did not receive pre-emergence herbicide applications due to historical field issues with these applications or field/environmental conditions.

Table 4. Seed treatments used and foliar fungicide and insecticide applications made on fields enrolled in the 2013 Rice Research Verification Program.

	Seed treatments	Foliar fungicide and insecticide applications			
Field location by county	Fungicide and/or insecticide seed treatment for control of diseases and insects attacking seedling rice	Fungicide applications for control of sheath blight/kernel smut/ false smut	Fungicide applications for control of rice blast	Insecticide applications for control of rice water weevil	Insecticide applications for control of rice stink bug/chinch bug
	(trade name and product rate/cwt seed)	--(trade name and product rate/acre)--			
Arkansas 1	RTST[a] + NipsIt INSIDE (1.92 fl oz)	------	------	-------	------
Arkansas 2	Apron XL (0.64 fl oz) + Maxim 4 FS (0.12 fl oz) + Zinc (8 oz cwt)	Quilt Xcel (14 oz)	------	------	------
Arkansas 3	NipsIt INSIDE (1.92 fl oz)	------	------	------	Karate (2.1 oz)
Chicot 1	CruiserMaxx Rice (7 fl oz) + Zinc (8 oz cwt)	Tilt (6 oz)	------	------	------
Chicot 2	CruiserMaxx Rice (7 fl oz)	------	------	------	Karate (1.8 oz)
Clark	RTST	------	------	------	
Clay	RTST	------	------	------	Lambda Cy (4 oz)
Conway	RTST	------	------	------	Lambda Cy (4 oz)
Cross	Apron XL (0.64 fl oz) + Maxim 4 FS (0.12 fl oz)	------	------	------	------
Desha	RTST	------	------	------	Karate (2.1 oz)
Independence	Apron XL (0.64 fl oz) + Maxim 4 FS (0.12 fl oz) + Release LC (2 fl oz)	Tilt (6 oz)	------	------	Lambda Cy (4 oz)
Jackson	CruiserMaxx Rice (7 fl oz)	------	------	------	------
Jefferson	-------	------	------	Belay (4.5 oz)	------
Lawrence	CruiserMaxx Rice (7 fl oz)	Quilt Xcel (21 oz)	------	------	------
Lee	CruiserMaxx Rice (7 fl oz) + Zinc (8 oz cwt)	------	------	------	Mustang Max(3.65 oz)
Lincoln	RTST	Quilt Xcel (16 oz)	------	------	Pro Axis (5.1 oz)

continued

Table 4. Continued.

Field location by county	Seed treatments	Foliar fungicide and insecticide applications			
	Fungicide and/or insecticide seed treatment for control of diseases and insects attacking seedling rice	Fungicide applications for control of sheath blight/kernel smut/ false smut	Fungicide applications for control of rice blast	Insecticide applications for control of rice water weevil	Insecticide applications for control of rice stink bug/chinch bug
	(trade name and product rate/cwt seed)	--(trade name and product rate/acre)---			
Phillips	Apron XL (0.64 fl oz) + Maxim 4 FS (0.12 fl oz)		------	------	------
Poinsett	CruiserMaxx Rice (7 fl oz)	------	------	------	-------
Prairie	------	------	------	------	Karate (2.1 oz)
Randolph	RTST	Quadris (8 oz)	------	------	-------
White	Release LC (2 fl oz)	Tilt (6 oz)	------	Mustang Max (3.5 oz)	-------
Yell	Apron XL (0.64 fl oz) +	Quilt Xcel (21 oz)	-------	-------	-------

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

Table 5. Rainfall and irrigation information for fields enrolled in the 2013 Rice Research Verification Program.

Field location by county	Rainfall	Irrigation[a]	Rainfall + irrigation
	(inches)	(acre-inches)	(inches)
Arkansas 1	3.90	22.00	25.9
Arkansas 2	6.10	30.00*	36.10
Arkansas 3	8.90	26.10	25.00
Chicot 1	8.05	30.00*	38.05
Chicot 2	16.80	30.00*	46.80
Clark	8.20	30.00*	38.20
Clay	16.73	40.06	56.79
Conway	8.17	30.00*	38.17
Cross	19.20	30.00*	49.20
Desha	5.30	17.50	22.80
Independence	18.37	27.17	45.54
Jackson	20.00	30.00*	50.00
Jefferson	4.70	15.50	20.20
Lawrence	17.26	30.00*	47.26
Lee	10.00	30.00*	40.00
Lincoln	6.65	30.00*	36.65
Phillips	7.75	30.00*	37.75
Poinsett	22.61	30.00*	52.61
Prairie	15.76	30.00*	45.76
Randolph	17.30	30.12	47.42
White	20.61	30.00*	50.61
Yell	13.83	20.95	34.78
Average	12.56	26.79	39.35

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

Table 6. Operating costs, total costs, and returns for the 2013 Rice Research Verification Program.

County	Operating costs	Operating costs	Returns to operating costs	Fixed costs	Total costs	Returns to total costs	Total costs
	($/acre)	($/bu)	($/acre)		($/acre)		($/bu)
Arkansas 1	651.36	2.97	805.24	85.71	737.07	719.53	3.37
Arkansas 2	711.32	3.31	737.65	99.09	810.41	638.56	3.77
Arkansas 3	493.53	2.26	964.97	96.66	590.19	868.30	2.71
Chicot 1	542.48	2.84	697.90	80.19	622.67	617.71	3.26
Chicot 2	508.16	2.73	703.40	69.40	577.56	634.00	3.11
Clark	671.00	3.35	643.53	91.72	762.72	551.81	3.81
Clay	692.52	3.96	481.72	90.03	782.55	391.69	4.47
Conway	642.78	2.58	905.87	103.23	746.00	802.65	3.00
Cross	469.54	2.58	724.89	77.38	546.92	647.51	3.01
Desha	564.85	3.49	494.95	55.09	619.94	439.86	3.83
Independence	658.15	3.41	617.94	89.21	747.36	528.74	3.87
Jackson	504.74	3.39	486.27	84.86	589.61	401.41	3.96
Jefferson	453.49	2.44	721.58	66.48	519.97	655.10	2.80
Lawrence	842.87	6.02	77.30	100.66	943.53	-23.36	6.74
Lee	688.64	3.05	834.47	89.66	778.30	744.80	3.44
Lincoln	765.85	3.53	562.49	97.57	863.42	464.91	3.98
Phillips	553.44	2.98	645.35	51.64	605.07	593.71	3.25
Poinsett	659.64	3.51	581.08	101.84	761.48	479.24	4.05
Prairie	597.60	3.23	554.82	76.45	674.05	478.37	3.64
Randolph	812.09	4.75	274.93	103.95	916.04	170.98	5.36
White	607.58	3.49	532.65	95.47	703.04	437.18	4.04
Yell	716.65	3.98	416.98	91.19	807.84	325.79	4.49
Average	627.65	3.36	612.09	86.25	713.90	525.84	3.82

Table 7. Summary of revenue and expenses per acre for fields enrolled in the Rice Research Verification Program, 2013.

Receipts	Arkansas 1	Arkansas 2	Arkansas 3	Chicot 1	Chicot 2	Clark	Clay
	(bu/acre)						
Yield	219	215	218	191	186	200	175
	($)						
Price received	6.65	6.74	6.69	6.49	6.51	6.57	6.71
Total crop revenue	**1,456,.59**	**1,448.97**	**1,458.50**	**1,240.38**	**1,211.56**	**1,314.53**	**1,174.25**
Operating expenses							
Seed	126.60	29.67	62.90	64.47	45.04	160.32	153.64
Fertilizers and nutrients	186.58	197.92	86.47	84.12	88.39	210.96	140.03
Chemicals	61.54	93.50	68.08	97.51	117.70	61.32	77.17
Custom applications	42.00	41.00	43.05	28.00	29.05	24.50	62.70
Diesel fuel	28.93	33.74	29.64	22.12	24.82	23.33	35.66
Repairs and maintenance	27.98	31.68	31.27	26.09	24.48	29.59	29.45
Irrigation energy costs	18.48	127.56	21.84	91.68	47.42	25.20	62.12
Labor, field activities	8.46	10.45	9.04	7.56	7.96	6.89	10.67
Other inputs and fees, pre-harvest	23.00	20.34	14.04	9.48	14.77	12.20	18.97
Post-harvest expenses	127.79	125.45	127.20	111.45	108.53	116.70	102.11
Total operating expenses	**651.36**	**711.32**	**493.53**	**542.48**	**508.16**	**671.00**	**692.52**
Returns to operating expenses	**805.24**	**737.65**	**964.97**	**697.90**	**703.40**	**643.53**	**481.72**
Capital recovery and fixed costs	85.71	99.09	96.66	80.19	69.40	91.72	90.03
Total specified expenses[a]	**737.07**	**810.41**	**590.19**	**622.67**	**577.56**	**762.72**	**782.55**
Returns to specified expenses	**719.53**	**638.56**	**868.30**	**617.71**	**634.00**	**551.81**	**391.69**
Operating expenses/yield unit	2.97	3.31	2.26	2.84	2.73	3.35	3.96
Total expenses/yield unit	3.37	3.77	2.71	3.26	3.11	3.81	4.47

continued

Table 7. Continued.

Receipts	Conway	Cross	Desha	Independence	Jackson	Jefferson	Lawrence
	(bu/acre)						
Yield	249	182	162	193	149	186	
	($)						
Price received	6.08	6.11	6.54	5.43	8.12	5.93	6.94
Total crop revenue	**1,548.65**	**1,194.43**	**1,059.80**	**1,276.09**	**991.02**	**1,175.07**	**920.17**
Operating expenses							
Seed	126.72	32.94	152.97	36.56	40.54	26.10	89.84
Fertilizers and nutrients	121.70	95.07	116.54	169.47	144.39	119.44	200.21
Chemicals	105.76	74.23	82.25	77.02	52.59	60.05	167.58
Custom applications	35.35	29.40	21.00	57.50	42.40	63.00	72.50
Diesel fuel	30.86	30.12	22.37	31.66	35.89	21.05	31.61
Repairs and maintenance	33.20	26.69	19.84	28.99	27.56	22.56	32.27
Irrigation energy costs	25.20	51.94	26.87	110.98	47.42	12.60	127.56
Labor, field activities	7.75	8.97	6.16	9.86	11.84	6.59	11.37
Other inputs and fees, pre-harvest	10.95	13.98	10.08	23.48	15.17	13.57	28.23
Post-harvest expenses	145.29	106.20	106.78	112.62	86.94	108.53	81.69
Total operating expenses	**642.78**	**469.51**	**564.85**	**658.15**	**504.74**	**453.49**	**842.87**
Returns to operating expenses	**905.87**	**724.89**	**494.95**	**617.94**	**486.27**	**721.58**	**77.30**
Capital recovery and fixed costs	103.23	77.38	55.09	89.21	84.86	66.48	100.66
Total specified expenses[a]	**746.00**	**846.92**	**619.94**	**747.36**	**589.61**	**519.97**	**943.53**
Returns to specified expenses	**802.65**	**647.51**	**439.86**	**528.74**	**401.41**	**655.10**	**-23.36**
Operating expenses/yield unit	2.58	2.58	3.49	3.41	3.39	2.44	6.02
Total expenses/yield unit	3.00	3.01	3.83	3.87	3.96	2.80	6.74

continued

Table 7. Continued.

Receipts	Lee	Lincoln	Philips	Poinsett	Prairie	Randolph	White	Yell	Average
	(bu/acre)								
Yield	226	217	186	188	185	171	174	180	191
	(bu/acre)								
Price received	6.74	6.12	6.45	6.60	6.23	6.36	6.55	6.30	6.51
Total crop revenue	**1,523.10**	**1,328.34**	**1,198.79**	**1,240.72**	**1,152.42**	**1,087.02**	**1,140.22**	**1,133.63**	**1,239.74**
Operating expenses									
Seed	42.83	194.68	40.10	43.91	33.35	160.32	23.03	29.68	78.01
Fertilizers and nutrients	201.49	159.68	138.70	179.26	124.60	186.83	149.47	182.76	149.28
Chemicals	115.40	106.75	116.07	143.09	94.20	92.58	118.97	159.89	97.42
Custom applications	49.70	73.50	56.00	59.20	49.00	40.00	56.40	56.00	46.88
Diesel fuel	39.03	25.85	15.33	32.67	19.79	37.82	39.75	32.25	29.29
Repairs and maintenance	29.83	31.71	16.81	32.25	24.08	33.40	33.70	30.99	28.38
Irrigation energy costs	47.42	25.20	47.42	25.20	127.56	128.07	51.94	89.08	60.85
Labor, field activities	11.38	7.80	4.69	9.18	6.30	11.63	14.20	11.53	9.10
Other inputs and fees, pre-harvest	19.70	14.07	9.79	25.08	10.77	21.65	18.62	19.44	16.70
Post-harvest expenses	131.87	126.62	108.53	109.70	107.95	99.78	101.53	105.03	111.74
Total operating expenses	**688.64**	**756.85**	**553.44**	**659.64**	**597.60**	**812.09**	**607.58**	**716.65**	**627.65**
Returns to operating expenses	**834.47**	**562.49**	**645.35**	**581.08**	**554.82**	**274.93**	**532.65**	**416.98**	**612.09**
Capital recovery and fixed costs	89.66	97.57	51.64	101.84	76.45	103.95	95.47	91.19	86.25
Total specified expenses[a]	**778.30**	**863.42**	**695.07**	**761.48**	**674.05**	**916.04**	**703.04**	**807.84**	**713.90**
Returns to specified expenses	**744.80**	**464.91**	**593.71**	**479.24**	**478.37**	**170.98**	**437.18**	**325.79**	**525.84**
Operating expenses/yield unit	3.05	3.53	2.98	3.51	3.23	4.75	3.49	3.98	3.36
Total expenses/yield unit	3.44	3.98	3.25	4.05	3.64	5.36	4.04	4.49	3.82

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

Table 8. Selected variable input costs per acre from fields enrolled in the 2013 Rice Research Verification Program.

County	Rice type	Seed	Fertilizers and nutrients	Herbicides	Insecticides	Fungicides and other	Machinery fuel and lube	Irrigation energy costs
Arkansas 1	CLXL745	126.60	186.58	61.54	-----	-----	28.93	18.48
Arkansas 2	Roy J	29.67	197.92	70.30	-----	23.21	33.74	127.56
Arkansas 3	CL151	62.90	86.47	61.46	6.62	-----	29.64	21.84
Chicot 1	CL152	64.47	84.12	90.49	-----	7.02	22.12	91.68
Chicot 2	Roy J	45.04	88.39	112.03	5.67	-----	24.82	47.42
Clark	CLXL745	160.32	210.96	61.32	-----	-----	23.33	25.20
Clay	CLXL745	153.64	140.03	64.57	12.60	-----	35.66	62.12
Conway	RTXL753	126.72	121.70	94.42	11.34	-----	30.86	25.20
Cross	Francis	32.94	95.07	74.23	-----	-----	30.12	51.94
Desha	CLXL745	152.97	116.54	75.63	6.62	-----	22.37	26.87
Independence	Roy J	36.56	169.47	57.40	12.60	7.02	31.66	110.98
Jackson	Roy J	40.54	144.39	52.59	-----	-----	35.89	47.42
Jefferson	Roy J	26.10	119.44	49.50	10.55	-----	21.05	12.60
Lawrence	CL111	89.84	200.21	126.67	-----	40.92	31.61	127.56
Lee	Roy J	42.83	201.49	109.63	5.77	-----	39.03	47.42
Lincoln	CLXL745	194.68	159.68	66.87	13.36	26.52	25.85	25.20
Phillips	Roy J	40.10	138.70	116.07	-----	-----	15.33	47.42
Poinsett	Jupiter	43.91	179.26	137.08	-----	6.11	32.67	25.20
Prairie	Roy J	33.35	124.60	88.44	5.76	-----	19.79	127.56
Randolph	CLXL745	160.32	186.83	66.71	-----	25.87	37.82	128.07
White	Roy J	23.03	149.47	100.28	5.53	13.13	39.75	51.94
Yell	Roy J	29.68	182.76	125.08	-----	34.81	32.25	89.08
Average	**-----**	**78.01**	**149.28**	**84.65**	**8.76**	**20.51**	**29.29**	**60.85**

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 by 31% in the last seven years. The University of Arkansas System Division of Agriculture 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. Beginning in 2010, an experiment was established at the RREC to determine the effect of different rates of nitrogen (N) fertilizer on the aroma, milling quality, and grain yield of aromatic rice varieties. In this test, six N rates were applied to seven aromatic rice varieties and one non-aromatic rice variety. Agronomic and yield data were collected. Hulled and milled seed were tested for the analysis of 2-acetyl-1-pyrroline (2A-P) concentration conducted at USDA-ARS Southern Regional Research Center, New Orleans, La. Results of the yield trials showed mixed varietal response to increased N fertilizer. Some varieties increased in yield while others remained unchanged or decreased with increased N fertilization. Total rice percentages from the three-year study varied significantly across varieties.

INTRODUCTION

Approximately 13.6 MM cwt of milled rice were imported to the United States in the fiscal year 2011/2012, an increase of 31% in the last seven years (USA Rice

Federation, 2009, 2012). The top supplying countries are Thailand, which produces high quality Jasmine rice, and India, which produces highly desired Basmati rice (USA Rice Federation, 2012). 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. International research on aromatic rice and N fertilizer indicate that genotype differences in N-use efficiency exists. Two international studies found excess N fertilizer had no effect on grain yield in native aromatic rice cultivars. Research was directed to determine the optimum fertility to produce the best aromatic qualities which will meet the consumers' demands.

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 2014.

A three-year study was conducted to determine the effect of different rates of N fertilizer on the aroma, milling quality, and grain yield of aromatic rice varieties. In 2010, the six aromatic rice varieties in this experiment were Dellrose, Jasmine 85, Jazzman, Jazzman II, JES, Sierra, and STG03-085, which is a University of Arkansas experimental line. Wells was included in the study as a non-aromatic control. Another UA experimental line, STG06-126, was determined to be non-aromatic and was dropped from the experiment. In 2011 and 2012, the seven aromatic rice varieties in this study were Dellrose, Jasmine 85, Jazzman, JES, Sierra, Jazzman II, and STG03-085. Wells was the non-aromatic control. The experiment was conducted using six N rates: 0, 30, 60, 90, 120, and 150 lb N/acre. All N was applied prior to permanent flood. Recommended rates of the herbicides clomazone (Command) and quinclorac (Facet) were applied at planting. Plant characteristic data were collected on heading date, plant height, and lodging. Grain weight and moisture content were recorded and are expressed as bushels per acre (bu/acre). Percentages of total and head rice were calculated. Hulled and milled seed were tested for the analysis of the aroma compound 2-acetyl-1-pyrroline (2A-P) concentration at the USDA-ARS Southern Regional Research Center, New Orleans, La. (Grimm et al., 2014).

RESULTS AND DISCUSSION

In 2013, 32 cross-pollinations were made to produce aromatic lines for screening. The F_1 plants from these crosses will be grown in the greenhouse during the winter to produce F_2 seed. The F_2 populations will be planted in 2014 at the Rice Research and Extension Center (RREC) for observation and selection.

Panicles were selected from 11 F_2 populations in 2013. The parents in these crosses were selected for their aromatic quality, high seed quality or high yield potential. Approximately 230 F_3 lines from 9 populations were shipped to the winter nursery in Puerto Rico to advance. The harvested seed from Puerto Rico will be planted at RREC for further observation and selections in 2014. Marker analysis will be conducted to detect or determine the characteristics of aroma, cooking quality, and blast resistance.

In 2013, 91 heterozygous lines from 11 F_4 and 15 F_3 populations were screened through marker-assisted selection for aroma and amylose content. Results of the screening of the 39 lines from the 11 F_4 populations helped to eliminate lines which did not meet breeding program requirements. Approximately 31% of the entries were homozygous aromatic and had *Pi-ta*, *Pi-b*, or *Pi-k* blast resistance. Twenty-six percent of the lines were discarded due to non-parental alleles.

Two preliminary yield trials were planted in 2013. A two-replication trial included 112 aromatic lines and a one-replication test included 39 aromatic lines. The 20 highest yielding lines were screened for aromatic flavor by conducting a taste test. The six 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 2014. Three lines have been entered in the 2014 Uniform Regional Rice Nursery (URRN).

Results of the aromatic rice and N rate study show grain yield responses to increased N fertilizer differed among varieties. In 2010, STG03-085 had the highest yield (134.7 bu/acre) at 90 lb N/acre. Dellrose, Jazzman, and Sierra were the least responsive to additional nitrogen. Yields of JES, Jasmine 85, STG06-126, and Wells increased with increasing rates of nitrogen. In 2011, yields of Dellrose, Jasmine 85, and STG03-085 decreased with increased nitrogen. Jazzman and Wells responded with increasing yields to the additional nitrogen. Jazzman II, JES, and Sierra showed no significant yield changes across the N rates. The non-aromatic control, Wells, had the highest yield in 2011, followed by JES (169.9 and 141.3 bu/acre, respectively). In 2012, yields of plots receiving 0 and 30 lb N/acre showed no significant difference. There was no significant difference in the yields of plots receiving 60, 90, 120, or 150 lb N/acre. STG03-085 had the highest yield (188.3 bu/acre) at 90 lb N/acre. STG03-085 and Jasmine 85 had significantly higher yields than other varieties. Sierra, Dellrose, and JES were the least responsive to increased nitrogen. Grain yields of Wells, Jazzman II, and Jazzman showed no significant difference.

Total rice percentage for 2010 resulted in significant differences across varieties and across nitrogen fertilizer treatments (Fig. 1). JES had the lowest and Jazzman had the highest percentage of total rice, 81.5% and 84.8%, respectively. The lowest milling scores were found in all varieties receiving 0 lb N/acre and the highest at 150 lb N/acre. In 2011, total rice was significantly different across varieties but not across N fertilizer treatments. STG03-085 had the lowest and Sierra had the highest milling score, 67.0% and 72.5% respectively. Total rice in 2012 resulted in significant differences across varieties and N fertilizer treatments (Fig. 2). JES had the lowest and Jazzman had the highest milling score, 58.0% and 60.3%, respectively. The lowest total rice percentage was found in all varieties receiving 0 lb N/acre and there was no significant difference among the plots receiving 90, 120, and 150 lb N/acre.

In a presentation at the 2014 Rice Technical Working Group, Grimm et al. (2014) stated that the 2A-P concentration fades with storage and milling. Grimm et al. reported there was no significant difference in the overall 2A-P concentrations between the milled and brown rice in the aromatic rice and nitrogen rate study (2014).

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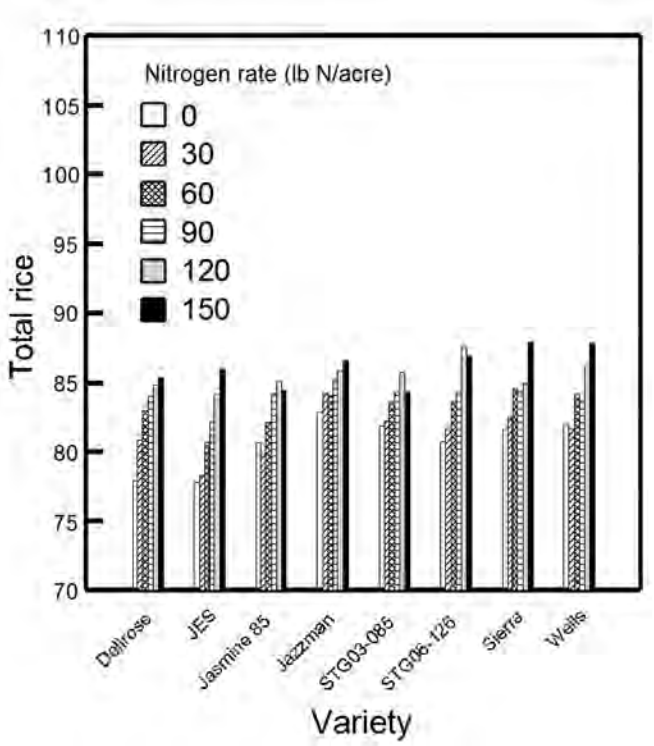

Fig. 1. Results of 2010 total rice (%) by variety and N rate.

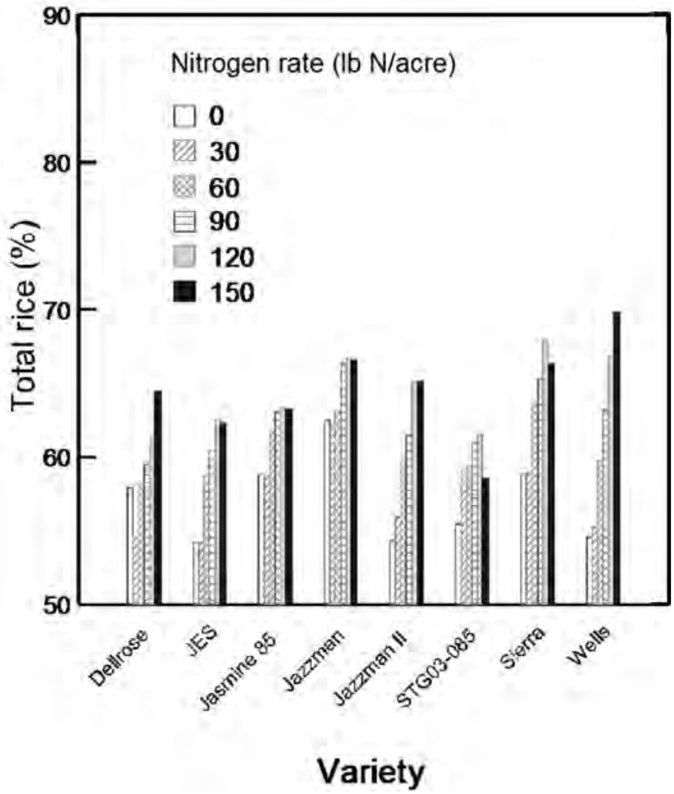

Fig. 2. Results of 2012 total rice (%) by variety and N rate.

BREEDING, GENETICS, AND PHYSIOLOGY

Development of Hybrid Rice Cultivars

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ABSTRACT

In 2013, hybrid rice was produced on more than 40% of the rice production acreage in Arkansas. Development of high-yielding hybrid rice cultivars has been ongoing at the University of Arkansas System Division of Agriculture Rice Research and Extension Center (RREC) near Stuttgart, Ark., since 2010. During 2013, 26 experimental hybrids were tested in an advanced yield trial (AYT) at the RREC along with the commercial hybrid checks XL723 and XL753 and the inbred line checks Roy J and Wells. Additionally, 87 experimental hybrids were tested in a preliminary yield trial (PYT) at the RREC. Yield values ranged from 123 bu/acre to 232 bu/acre for experimental hybrids in the AYT. In the PYT, yield values ranged from 160 bu/acre to 272 bu/acre. Variability was observed for both agronomic and quality related traits in both yield trials.

A large scale effort was also placed on the evaluation of existing germplasm and development of new breeding populations to address quality issues associated with hybrids in 2013. Existing germplasm was assessed on the basis of agronomic performance, apparent disease resistance, and grain quality. In total, 464 unique crosses were made using adapted germplasm as at least one parent to address agronomic and quality issues often associated with hybrids. These breeding populations will be evaluated in the field in 2014.

Several steps were taken to improve the overall efficiency of the hybrid rice breeding program. These included mechanization of the program, application of improved breeding methods, and use of molecular markers. Further improvements will be made during 2014.

INTRODUCTION

The hybrid rice program began in 2010, utilizing accessions of diverse germplasm found in the United States Department of Agriculture (USDA) rice core collection (Yan et al., 2011). While this germplasm served as an initial base for the hybrid program, much work is needed to identify genotypes adapted to the mid-South (Berger et al., 2013). A major goal of the hybrid program in 2013 was to evaluate existing male sterile, restorer, and maintainer lines for agronomic and grain quality desirability. Evaluations were made both in the field and through the use of molecular markers. Improvement of this germplasm began in 2013 and will continue as the program grows. Both preliminary and advanced yield tests were conducted at the RREC during 2013. Evaluations were made and compared with commercially available check cultivars. Additionally, development of new breeding populations utilizing adapted southern long-grain germplasm began during 2013. A major focus of the upcoming year will be continued integration of new breeding material and technologies to improve the overall efficiency of the hybrid rice breeding program.

PROCEDURES

During the 2013 growing season, the hybrid rice breeding program tested 26 new hybrid combinations in an advanced yield test (AYT) at the Rice Research and Extension Center (RREC) near Stuttgart, Ark. Additionally, 87 experimental hybrids were tested in a preliminary yield test (PYT). Standard agronomic practices were followed based on recommendations for Arkansas. Agronomic measurements taken included early season plant stands, 50% heading date, purity notes, plant height, lodging, and grain yield. Plots were harvested with Wintersteiger plot combines at harvest maturity. Plot weight and moisture were taken at harvest. Quality characteristics including increased amylose content, decreased chalkiness, and improved gelatinization temperature were also evaluated.

A large scale effort was made to develop new breeding populations for identification of male-sterile, maintainer, and restorer lines using known sources and adapted germplasm. In total, 464 unique crosses were made in 2013. The goal is to incorporate typical U.S. long-grain quality into the hybrid breeding pipeline. Of the 464 crosses, 34 crosses were made for improvement of 2-line male steriles, 62 crosses were made for improvement of B-lines, 4 backrosses were made for development of new A/B pairs and 362 crosses were made for development of male (restorer) lines.

Breeding objectives focused on improved agronomic traits, quality characteristics, disease resistance, and traits important to hybrid seed production. Agronomic traits included decreased plant height, earlier maturation, and improved lodging resistance. Quality characteristics including increased amylose content, decreased chalkiness, and improved gelatinization temperature. Traits important to the production of hybrid seed including large, exerted stigmas for effective cross pollination, restorer genes from unadapted sources, and improved combining ability. Segregating populations were also grown and selections were made.

Isolated hybrid seed production tests were located in several bays at the RREC in 2013. New small-plot hybrid production methods were tested. Development of more efficient hybrid test cross methods will aid in production of new hybrid combinations. Further improvements will be made upon the methods in 2014.

RESULTS AND DISCUSSION

During 2013, 26 experimental hybrids were tested in the AYT at the RREC. Heading dates (days from emergence to heading) for experimental hybrids ranged from 80 days to 96 days (Table 1). For several hybrid combinations, heading dates were similar to those of the check hybrids XL723 (81 days) and XL753 (85 days). Plant heights ranged from 37 inches to 46 inches which were similar to the check cultivars Wells and Roy J, and check hybrids XL723 and XL753. Grain yield of experimental hybrids ranged from 123 bu/acre to 232 bu/acre. Experimental hybrids 13UAXH-61, 13UAXH-64, 13UAXH-67, and 13UAXH-74 produced yields similar to that of XL723 and XL753. In total, 18 experimental hybrid yields exceeded that of the check cultivar Roy J. Variability was noted for milling yields, amylose content, gel type, and cook type.

A larger set of experimental hybrids were planted in the 2013 PYT. This set of experimental hybrids was more variable in terms of heading date, plant heights, and grain yield and quality. Heading dates of the 87 experimental hybrids ranged from 65 days to 96 days. Plant heights ranged from 37 inches to 51 inches. Grain yields ranged from 144 bu/acre to 272 bu/acre. A subset of these lines with amylose contents greater than 20 g/kg and the commercial checks Roy J and Francis are displayed in Table 2. These experimental hybrids are the most promising in terms of grain quality.

Crosses focusing on the development of sterile, maintainer, and restorer lines resulted in 464 new combinations. During the fall and winter of 2013, 34 F_1 populations for s-line development, 36 F_1 populations for maintainer (B-line) development, and 60 F_1 populations for male (restorer) line development were grown in the greenhouse to rapidly advance generations. The remaining F_1 populations will be planted in the field during 2014.

A total of 140 hybrid combinations were produced for testing during 2014. The winter nursery in Lajas, Puerto Rico, is being evaluated as a location to develop new hybrid combinations. Test crosses between male (restorer) and sterile lines will be made during the spring of 2014. The long term goal is to develop 1000 new hybrid combinations to test per year.

SIGNIFICANCE OF FINDINGS

The research presented shows the significant advances made by the hybrid rice breeding program during 2013. Further growth of the program will continue in 2014. Development of improved sterile lines (both 2- and 3-line) and male (restorer) lines which began in 2013 will be further expanded on in 2014. Additionally, new projects will be developed to answer questions pertaining to hybrid rice breeding and production. Continued research promises to identify high yielding hybrids adapted to Arkansas.

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Table 1. Agronomic data for 26 experimental hybrids and check cultivars grown in the Advanced Yield Trial (AYT) at the RREC in 2013.

Line	Yield	Maturity date	Plant height	Lodging	Head rice	Total rice	Amylose	Gel type	Cook type
	(bu/acre)	(50% heading)	(inches)	(0-9)	(%)	(g/kg)			
XL723	246	81	40	0	64.6	71.3	20.2	Int High Mix	Long
13UAXH-61	232	86	41	4	57.3	69.1	13.6	Int Low Mix	Atypical
13UAXH-67	230	81	41	1	59.4	68.6	13.2	Int	Atypical
XL753	226	85	40	0	66.4	71.6	19.9	Int	Long
13UAXH-64	226	84	40	5	60.9	69.2	12.2	Int High Mix	Atypical
13UAXH-74	226	81	43	1	62.1	67.9	12.8	Int Low Mix	Atypical
13UAXH-65	217	80	40	0	59.6	67.7	12.4	Int High Low Mix	Atypical
13UAXH-53	217	87	41	0	59.4	67.5	20.4	Int Low Mix	Long
13UAXH-56	215	84	45	0	61.9	67.5	20.7	Int Low Mix	Long
13UAXH-54	207	88	45	0	62.1	68.7	20.4	Int	Long
13UAXH-42	205	87	41	0	60.9	67.6	14.8	Int High Mix	Atypical
13UAXH-71	201	84	38	2	61.3	68.7	17.2	Int	Atypical
13UAXH-81	199	84	38	0	60.4	67.8	13.6	Int Low Mix	Atypical
13UAXH-6	199	89	46	0	58.7	67.2	21.2	Int	Long
13UAXH-84	197	84	42	0	60.8	68.0	13.6	Int Low Mix	Atypical
13UAXH-44	196	84	44	0	59.4	66.7	15.6	Int Low Mix	Atypical
13UAXH-5	192	95	41	0	57.8	66.5	22.3	Int Low Mix	Long
13UAXH-59	192	83	38	0	62.1	68.7	20.7	Int Low Mix	Long
13UAXH-8	191	96	44	0	58.1	66.5	23.7	Int Low Mix	Long
13UAXH-82	190	83	43	1	62.2	68.8	12.4	Int	Atypical
Roy J	189	92	40	0	63.4	70.0	23.0	Int	Long
13UAXH-41	186	86	43	1	60.9	67.7	15.4	Int Low Mix	Atypical
Wells	186	91	41	0	63.7	71.2	22.5	Int	Long
13UAXH-4	183	88	45	0	56.4	66.6	22.2	Int	Long
13UAXH-66	180	80	39	1	59.3	69.5	13.1	Int	Atypical
13UAXH-47	176	89	41	0	61.8	68.1	16.1	Int High Low Mix	Atypical
13UAXH-87	170	81	38	1	63.6	68.7	14.5	Int	Atypical
13UAXH-79	163	83	40	0	61.6	68.9	19.9	Int Low Mix	Long
13UAXH-11	148	83	37	0	61.2	67.8	21.0	Int Low Mix	Long
13UAXH-3	123	93	46	0	52.9	65.3	21.2	Int	Long
LSD ($P = 0.05$)	27.9	4.9	8.2	-	3.1	1.1	---	---	---

Table 2. Agronomic data for 23 experimental hybrids and check cultivars grown in the Preliminary Yield Trial (PYT) at the Rice Research and Extension Center in 2013.

Line[a]	Yield	Maturity date	Plant height	Lodging	Head rice	Total rice	Amylose	Gel type	Cook type
	(bu/acre)	(50% heading)	(inches)	(0-9)	(%)	(g/kg)			
13UAXH-60	272	84	46	0	67.1	58.2	20.1	High Int Mix	Atypical
13UAXH-12	269	95	49	0	67.3	58.0	20.8	High Int Mix	Atypical
13UAXH-49	268	84	44	0	66.6	53.7	20.7	Low Int Mix	Atypical
13UAXH-53	258	81	44	0	65.6	55.1	20.3	Int Low Mix	Long
13UAXH-1	254	94	50	0	65.6	51.9	21.5	Int Low Mix	Long
13UAXH-6	250	91	51	0	67.9	56.9	20.0	Int High Mix	Long
13UAXH-70	247	83	41	0	66.2	50.4	20.4	Int High Mix	Long
13UAXH-7	244	92	44	0	66.5	55.2	23.0	Int	Long
13UAXH-8	244	93	48	1	66.2	56.0	21.8	Int Low Mix	Long
13UAXH-54	242	81	45	0	66.9	53.7	20.0	Int High Mix	Long
13UAXH-55	241	81	44	0	66.7	54.2	20.8	Int Low Mix	Long
13UAXH-56	226	81	44	0	66.3	49.9	20.0	Int Low High Mix	Long
13UAXH-58	226	.	44	0	66.7	57.3	23.4	Int High Mix	Long
13UAXH-4	224	87	49	0	64.7	53.8	21.0	High Int Mix	Atypical
13UAXH-69	223	73	42	1	68.7	46.5	20.4	Int High Mix	Long
13UAXH-57	222	73	41	1	69.0	55.1	23.4	Int	Ex Hi Amy
13UAXH-51	215	80	43	0	67.1	58.1	22.5	Int	Long
13UAXH-63	215	74	44	4	67.4	54.8	20.3	Int High Mix	Long
13UAXH-14	209	87	46	0	65.1	50.3	21.1	Int	Long
13UAXH-10	204	93	44	0	65.8	51.1	23.8	Int	Ex Hi Amy
13UAXH-59	200	74	42	0	68.0	53.5	20.2	Int	Long
Francis	198	85	42	0	71.7	64.6	23.3	Int	Long
Roy J	196	87	46	0	69.8	65.4	22.8	Int	Long
13UAXH-5	190	87	44	0	66.7	56.1	21.2	Int Low High Mix	Long
13UAXH-9	184	80	44	0	68.4	60.3	23.7	Int Low Mix	Ex Hi Amy
RU0801081	160	83	42	0	69.9	62.5	23.1	Int	Long

[a] Subset of lines tested in 2013 at the RREC.

BREEDING, GENETICS, AND PHYSIOLOGY

Molecular Characterization of Parental Lines and Hybrids In a Hybrid Rice Breeding Program

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ABSTRACT

Hybrid rice development has been ongoing at the University of Arkansas System Division of Agriculture Rice Research and Extension Center (RREC) near Stuttgart, Ark., for over three years. During this time, much effort has been devoted to the phenotypic and genotypic characterization of superior male-sterile (both 2- and 3-line) and restorer lines for use in hybrid development. During the course of the program, experimental hybrids have been developed and evaluated in local and regional nurseries.

In 2013, materials from the RREC Hybrid Rice Breeding Program were characterized on a molecular level. The objective was to determine the genetic purity of the male-sterile and restorer lines, and allele tracking of the hybrid lines. Twelve male-sterile lines, 22 restorers, and 26 hybrids were analyzed in replicates of 10 with 23 molecular markers. Twelve of the markers were linked to agronomic traits of interest including cooking quality, disease resistance, leaf texture, and plant height. The remaining markers were selected for fingerprinting across the genome.

The marker data indicated that 25% of the male-sterile lines and 91% of the restorer lines were genotypically pure and ready to use as parental material. Variability was observed for both target and random loci throughout the genome. Of the 12 male-sterile lines, three were genotypically pure for target loci including amylose content, gelatinization temperature, and aroma. Remaining male-sterile lines were segregating at low to high levels depending on the trait. They were fairly uniform in plant height, amylose content, and gelatinization temperature, but segregating for leaf surface texture, aroma, and the rice blast resistance gene *Pi-ta*. In general, the restorers were less variable for both target and random loci. Hybridity was confirmed in all 26 experimental hybrid lines.

INTRODUCTION

Since hybrid rice was first commercialized in the early 1970s in China, rice growers have enjoyed increased yields and new opportunities to incorporate desirable traits in rice crops (Xu, 2003). Use of marker-assisted selection (MAS) during hybrid production can be a powerful tool for the hybrid rice breeders to evaluate and characterize germplasm resources, aid in selection of agronomic traits, track gene introgression, predict hybrid performance, and to monitor seed quality in the final stages of the seed production process (Xu, 2003). Most importantly, using DNA markers can confirm hybridity and seed purity in an evaluation conducted on a level not affected by time or environmental influences.

Desirable DNA markers should be able to detect a high frequency of polymorphism, exhibit codominance, be abundant and enable whole genome coverage, and have high duplicability. Ideal markers for MAS have to be suitable for high-throughput analysis and multiplexing, be cost-effective, require only small amounts of DNA, and be user friendly. Factors to consider when choosing DNA markers are the number of alleles, polymorphism information content (PIC) value, and whether or not they are informative for a particular breeding population (Xu, 2003).

In 2013, materials from the Rice Research and Extension Center (RREC) Hybrid Rice Breeding Program were screened with molecular markers linked to the rice blast resistance genes *Pi-b*, *Pi-k*, *Pi-ta*, and *Pi-z* (Conaway-Bormans et al., 2003; Fjellstrom et al., 2004, 2006; Wang et al., 2010) and the cooking quality traits of amylose content, gelatinization temperature, and aroma (Bao et al., 2002; Bergman et al., 2001; McClung et al., 2004). Plant height was assessed using RM1339 linked to *sd1* (Sharma et al., 2009), and leaf texture was predicted using a glabrous-linked single nucleotide polymorphism (SNP) marker GlabSNP (Fjellstrom, pers. com.). The remaining ten rice microsatellite markers were scattered throughout the genome and used for DNA fingerprinting purposes.

The objective of this ongoing study is to apply DNA marker technology to assist with the mission of the RREC Hybrid Rice Breeding Program. 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 hybridity and track gene introgression, and (iii) ensuring seed quality and uniformity by eliminating off types.

PROCEDURES

Sampling of the initial materials was performed by using a high-throughput embryo extraction method to obtain total genomic DNA from sterile line and hybrid seed. De-hulled seed was placed into 2-ml ScrewCap Mictrotubes or a 96-well block with about 20 1-mm glass beads per sample. The seed samples were processed in a BeadBeater-96 (BioSpec Products, Bartlesville, Okla.). The endosperm was removed and the 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).

In instances where destruction of the sample was not possible, leaf tissue was sampled. Leaf tissue from individually tagged field plants or greenhouse-grown seedlings was collected in manila coin envelopes kept in plastic bags on ice until arrival at the molecular genetics lab. The leaf tissue was stored at -80 °C until sampled. Total genomic DNA was extracted from the leaf tissue using the above-mentioned alkaline extraction method (Xin et al., 2003). Each DNA sample was arrayed in a 96-well format and 2 µl of each sample was used as a starting template for each 25 µl polymerase chain reaction (PCR) analysis.

All molecular markers used were PCR-based microsatellite markers or allele-specific single nucleotide polymorphism (SNP) markers. Primers were pre-labeled with attached fluorophores. Analysis by PCR was performed with either HEX, FAM, or NED labeled primers by adding template and enough bovine serum albumin and polyvinylpyrrolidone 40 in the cocktail mix to have final concentrations of 0.1% and 1%, respectively (Xin et al., 2003) and cycling the reactions in a Mastercycler Gradient S thermal cycler (Eppendorf North America, Inc., Westbury, N.Y.). 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 3730 DNA Analyzer. Data analysis was conducted using GeneMapper Software (Applied Biosystems, Foster City, Calif.).

RESULTS AND DISCUSSION

All lines sampled amplified homozygous alleles at the *sd1* locus indicating semidwarf plant height (Tables 1 and 2). Molecular data on the 12 male-sterile lines showed the most variability when screened with molecular markers linked to the traits of leaf surface texture, aroma, and rice blast disease resistance. The majority of the male-sterile lines amplified alleles linked to medium-high gelatinization temperatures (Table 1). One third of the male-sterile lines amplified alleles linked to a pubescent leaf-type, 75% amplified alleles linked to low amylose content while the remaining 25% were segregating from low to high, and 33% were homozygous aromatic with an additional 25% segregating for aroma (Table 1).

In the category of rice blast disease resistance, one third of the male-sterile lines were homozygous for the resistant allele at the *Pi-b* locus, but only 17% amplified homozygous resistant alleles at the *Pi-ta* locus with 58% segregating for *Pi-ta* resistance (Table 3). Only two of the male-sterile lines amplified a resistant allele at either the *Pi-k* or the *Pi-z* locus, and they were segregating for the trait (Table 3). The data indicates that the rest of the male-sterile lines are completely susceptible at these loci (Table 3).

Analysis of the 22 restorer lines indicates more uniformity in plant type with 91% amplifying glabrous leaf surface alleles and the remaining segregating (Table 1). Ten of the 22 lines amplified low amylose content alleles with RM190, with seven lines amplifying alleles indicating high amylose content and four lines intermediate. Only one of the restorer lines is segregating at the *Waxy* locus (Table 1). Half of the restorer lines should have medium to high gelatinization temperature and a little over a third should have a low gelatinization temperature. Four of the restorer lines are still segregating for this trait (Table 1). Almost a third of the restorer lines are also aromatic, with one line segregating for aroma. The remaining restorer lines are non-aromatic (Table 1).

Restorer lines exhibited more rice blast disease resistance potential than the male-sterile lines at three of the four loci tested. None have resistance at the *Pi-z* locus (Table 3). Almost one third are resistant at the *Pi-b* locus, 86% amplified resistant alleles at the *Pi-k* locus, and 41% have *Pi-ta* resistance (Table 3).

Hybridity was confirmed with all 26 hybrid lines sampled. All 26 lines amplified homozygous alleles at the *sd1* locus indicating semi-dwarf plant height, and 65% should have pubescent leaves with an additional 15% segregating for pubescence (Table 2). One hybrid line should have intermediate amylose, and 54% are segregating at the *Waxy* locus (Table 2). Forty-two percent of the hybrid lines amplified homozygous alleles indicating low amylose content and there is good correlation between the marker data with the obtained results for apparent amylose content phenotype (Table 2) (Berger et al., 2013). More than three quarters of the hybrid lines should have medium to high gelatinization temperatures, with the remaining segregating for gelatinization temperature (Table 2). One hybrid line is aromatic, while 54% of the lines are segregating for the trait (Table 2).

Marker data indicates that the hybrid lines have potential for rice blast disease resistance with most of the lines segregating for either *Pi-b*, *Pi-k*, or *Pi-ta* resistance (Table 4). One hybrid line is homozygous for *Pi-b* resistance, one is homozygous for *Pi-k* resistance, and six of the hybrid lines are homozygous for *Pi-ta* resistance (Table 4). None of the lines are homozygous for more than one rice blast resistance locus tested (Table 4).

SIGNIFICANCE OF FINDINGS

Marker screening of parental and hybrid lines revealed that progress is being made in the RREC Hybrid Rice Breeding Program. Applying molecular marker technology to the Hybrid Rice Breeding Program enabled the breeder to assess the status of the program after three years' effort, and eliminate those materials that are not desirable for inclusion in future hybrid rice breeding efforts.

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Table 1. Parental lines screened with markers linked to plant type and cooking quality traits.

Sample Name	Type	*sd1* RM1339	Glabrous GlabSNP	*Waxy* RM190	*Alk* Alk SNP	2AP Aroma
13UAXS-1	Sterile	Semi-dwarf	Glabrous	Low Amylose	Segregating	Non-Aromatic
13UAXS-2	Sterile	Semi-dwarf	Segregating	Segregating	Med-High Gel	Non-Aromatic
13UAXS-3	Sterile	Semi-dwarf	Pubescent	Low Amylose	Med-High Gel	Aromatic
13UAXS-4	Sterile	Semi-dwarf	Pubescent	Low Amylose	Med-High Gel	Aromatic
13UAXS-5	Sterile	Semi-dwarf	Pubescent	Low Amylose	Med-High Gel	Aromatic
13UAXS-6	Sterile	Semi-dwarf	Segregating	Segregating	Med-High Gel	Segregating
13UAXS-7	Sterile	Semi-dwarf	Glabrous	Segregating	Med-High Gel	Segregating
13UAXS-8	Sterile	Semi-dwarf	Pubescent	Low Amylose	Med-High Gel	Aromatic
13UAXS-9	Sterile	Semi-dwarf	Segregating	Low Amylose	Med-High Gel	Segregating
13UAXS-10	Sterile	Semi-dwarf	Glabrous	Low Amylose	Med-High Gel	Non-Aromatic
13UAXS-11	Sterile	Semi-dwarf	Segregating	Low Amylose	Med-High Gel	Non-Aromatic
13UAXS-12	Sterile	Semi-dwarf	Glabrous	Low Amylose	Med-High Gel	Non-Aromatic
11_77	Restorer	Semi-dwarf	Glabrous	Low Amylose	Med-High Gel	Non-Aromatic
188R	Restorer	Semi-dwarf	Glabrous	Low Amylose	Low Gel	Non-Aromatic
190R	Restorer	Semi-dwarf	Glabrous	Low Amylose	Med-High Gel	Non-Aromatic
193R	Restorer	Semi-dwarf	Glabrous	Low Amylose	Med-High Gel	Non-Aromatic
351R	Restorer	Semi-dwarf	Glabrous	High Amylose	Low Gel	Non-Aromatic
352R	Restorer	Semi-dwarf	Glabrous	High Amylose	Med-High Gel	Aromatic
353R	Restorer	Semi-dwarf	Glabrous	Intermediate	Segregating	Non-Aromatic
367R	Restorer	Semi-dwarf	Glabrous	Low Amylose	Med-High Gel	Non-Aromatic
370R	Restorer	Semi-dwarf	Glabrous	Low Amylose	Low Gel	Non-Aromatic
551	Restorer	Semi-dwarf	Segregating	Low Amylose	Segregating	Segregating
376R	Restorer	Semi-dwarf	Glabrous	Low Amylose	Med-High Gel	Non-Aromatic
377R	Restorer	Semi-dwarf	Glabrous	High Amylose	Low Gel	Aromatic
378R	Restorer	Semi-dwarf	Glabrous	Low Amylose	Med-High Gel	Non-Aromatic
385R	Restorer	Semi-dwarf	Glabrous	High Amylose	Low Gel	Aromatic
596R	Restorer	Semi-dwarf	Glabrous	Intermediate	Med-High Gel	Aromatic
598R	Restorer	Semi-dwarf	Glabrous	Intermediate	Low Gel	Non-Aromatic
11_2527	Restorer	Semi-dwarf	Glabrous	Segregating	Segregating	Non-Aromatic
11_3035	Restorer	Semi-dwarf	Glabrous	High Amylose	Segregating	Non-Aromatic

continued

Table 1. Continued.

Sample Name	Type	*sd1* RM1339	Glabrous GlabSNP	*Waxy* RM190	*Alk* Alk SNP	2AP Aroma
11_3137	Restorer	Semi-dwarf	Glabrous	Low Amylose	Med-High Gel	Non-Aromatic
11_5801	Restorer	Semi-dwarf	Glabrous	High Amylose	Med-High Gel	Aromatic
11_6073	Restorer	Semi-dwarf	Segregating	Intermediate	Med-High Gel	Non-Aromatic
12_6161	Restorer	Semi-dwarf	Glabrous	High Amylose	Low Gel	Aromatic

Table 2. Hybrid lines screened with markers linked to plant type and cooking quality traits compared with conventional cultivars.

Sample Name	*sd1* RM1339	Glabrous GlabSNP	*Waxy* RM190	*Alk* Alk SNP	2AP Aroma	Apparent Amylose
13UAXH-76	Semi-dwarf	Pubescent	Low Amylose	Med-High Gel	Segregating	12.3
13UAXH-88	Semi-dwarf	Segregating	Segregating	Med-High Gel	Non-Aromatic	11.8
13UAXH-61	Semi-dwarf	Pubescent	Low Amylose	Segregating	Segregating	14.6
13UAXH-37	Semi-dwarf	Pubescent	Low Amylose	Segregating	Segregating	14.8
13UAXH-1	Semi-dwarf	Pubescent	Segregating	Segregating	Non-Aromatic	21.5
13UAXH-91	Semi-dwarf	Pubescent	Segregating	Med-High Gel	Segregating	-
13UAXH-39	Semi-dwarf	Pubescent	Segregating	Med-High Gel	Segregating	19.5
13UAXH-51	Semi-dwarf	Segregating	Segregating	Med-High Gel	Segregating	22.5
13UAXH-79	Semi-dwarf	Glabrous	Segregating	Med-High Gel	Segregating	18.2
13UAXH-17	Semi-dwarf	Pubescent	Segregating	Med-High Gel	Aromatic	19.5
13UAXH-3	Semi-dwarf	Pubescent	Segregating	Med-High Gel	Segregating	19.6
13UAXH-64	Semi-dwarf	Pubescent	Low Amylose	Med-High Gel	Segregating	12.5
13UAXH-40	Semi-dwarf	Pubescent	Intermediate	Med-High Gel	Segregating	13.0
13UAXH-4	Semi-dwarf	Pubescent	Segregating	Med-High Gel	Non-Aromatic	21.0
13UAXH-18	Semi-dwarf	Segregating	Low Amylose	Med-High Gel	Segregating	13.1
13UAXH-74	Semi-dwarf	Pubescent	Low Amylose	Segregating	Segregating	13.4
13UAXH-5	Semi-dwarf	Pubescent	Segregating	Segregating	Non-Aromatic	21.2
13UAXH-92	Semi-dwarf	Glabrous	Low Amylose	Med-High Gel	Non-Aromatic	-
13UAXH-90	Semi-dwarf	Pubescent	Segregating	Med-High Gel	Non-Aromatic	-
13UAXH-54	Semi-dwarf	Glabrous	Segregating	Med-High Gel	Non-Aromatic	20.0
13UAXH-82	Semi-dwarf	Glabrous	Low Amylose	Med-High Gel	Non-Aromatic	10.9
13UAXH-20	Semi-dwarf	Pubescent	Low Amylose	Med-High Gel	Segregating	11.8
13UAXH-6	Semi-dwarf	Pubescent	Segregating	Med-High Gel	Non-Aromatic	21.2
13UAXH-75	Semi-dwarf	Pubescent	Low Amylose	Med-High Gel	Segregating	13.3
13UAXH-83	Semi-dwarf	Glabrous	Low Amylose	Med-High Gel	Non-Aromatic	11.0
13UAXH-56	Semi-dwarf	Segregating	Segregating	Segregating	Non-Aromatic	20.0
Jupiter[a]	Semi-dwarf	Glabrous	Low Amylose	Low Gel	Non-Aromatic	-
Wells[b]	Tall	Glabrous	Intermediate	Med-High Gel	Non-Aromatic	22.5
ZHE_733	Semi-dwarf	Pubescent	High Amylose	Med-High Gel	Non-Aromatic	-
JES	Semi-dwarf	Pubescent	Low Amylose	Low Gel	Aromatic	-

[a] Typical U.S. medium-grain rice.

[b] Typical U.S. long-grain rice.

Table 3. Parental lines screened with markers linked to rice blast disease resistance genes.

Sample name	*Pi-b* RM208	*Pi-k* RM224	*Pi-ta* *Pi-indica*	*Pi-z* AP5659-1	*Pi-z* AP5659-5
13UAXS-1	S	S	R	S	S
13UAXS-2	S	Segregating	Segregating	S	S
13UAXS-3	S	S	S	S	S
13UAXS-4	S	S	Segregating	S	S
13UAXS-5	R	S	Segregating	S	S
13UAXS-6	Segregating	S	Segregating	S	S
13UAXS-7	S	S	Segregating	S	S
13UAXS-8	R	S	Segregating	S	S
13UAXS-9	Segregating	S	Segregating	S	Segregating
13UAXS-10	R	S	R	S	S
13UAXS-11	S	S	S	S	S
13UAXS-12	R	S	S	S	S
11_77	S	R	S	S	S
188R	S	R	R	S	S
190R	R	R	S	S	S
193R	R	R	S	S	S
351R	S	R	S	S	S
352R	S	R	R	S	S
353R	Segregating	R	S	S	S
367R	S	R	R	S	S
370R	R	R	S	S	S
551	R	S	S	S	S
376R	S	R	R	S	S
377R	R	R	R	S	S
378R	S	R	R	S	S
385R	R	R	R	S	S
596R	S	R	R	S	S
598R	S	R	S	S	S
11_2527	S	R	S	S	S
11_3035	S	R	Segregating	S	S
11_3137	S	R	S	S	S
11_5801	Segregating	S	R	S	S
11_6073	S	S	S	S	S
12_6161	S	R	S	S	S

Table 4. Hybrid lines screened with markers linked to rice blast disease resistance genes and compared with conventional cultivars.

Sample name	*Pi-b* RM208	*Pi-k* RM224	*Pi-ta* *Pi-indica*	*Pi-z* AP5659-1	*Pi-z* AP5659-5
13UAXH-76	Segregating	Segregating	Segregating	S	S
13UAXH-88	Segregating	Segregating	Segregating	S	S
13UAXH_61	Segregating	Segregating	R	S	S
13UAXH_37	Segregating	Segregating	Segregating	S	S
13UAXH-1	S	Segregating	Segregating	S	S
13UAXH-91	S	R	Segregating	S	S
13UAXH-39	Segregating	Segregating	S	S	Segregating
13UAXH-51	Segregating	S	Segregating	S	S
13UAXH-79	Segregating	Segregating	R	S	S
13UAXH-17	S	S	Segregating	S	S
13UAXH-3	S	Segregating	Segregating	S	S
13UAXH-64	Segregating	Segregating	Segregating	S	S
13UAXH-40	Segregating	Segregating	Segregating	S	Segregating
13UAXH-4	S	Segregating	Segregating	S	S
13UAXH-18	S	Segregating	Segregating	S	S
13UAXH-74	R	Segregating	S	S	S
13UAXH-5	Segregating	Segregating	Segregating	S	S
13UAXH-92	Segregating	Segregating	R	S	S
13UAXH-90	S	Segregating	Segregating	S	S
13UAXH-54	S	Segregating	R	S	S
13UAXH_82	Segregating	Segregating	R	S	S
13UAXH-20	S	Segregating	Segregating	S	S
13UAXH-6	S	Segregating	Segregating	S	S
13UAXH-75	Segregating	Segregating	Segregating	S	S
13UAXH-55	Segregating	Segregating	R	S	S
13UAXH-56	S	S	Segregating	S	S
Jupiter[a]	S	R	S	S	S
Wells[b]	S	R	S	S	S
ZHE_733	S	S	S	S	S
JES	S	S	S	R	R

[a] Typical U.S. medium-grain rice.

[b] Typical U.S. long-grain rice.

Lakast, A High Yielding, Very Short Season, Long-Grain Rice Variety

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ABSTRACT

LaKast, a new very short season, very high yielding, long-grain rice cultivar was derived from the cross LaGrue//Katy/Starbonnet/3/LaGrue. LaKast has been approved for release to qualified seed growers for the summer of 2014. The major advantages of Lakast are its high yield potential, long kernel length, low chalk, and early maturity. LaKast is a standard height long-grain rice cultivar with lodging resistance similar to Wells and Francis. LaKast is susceptible to rice blast, sheath blight, and bacterial panicle blight, and moderately susceptible to straighthead.

INTRODUCTION

LaKast was developed in the rice improvement program at the University of Arkansas System Division of Agriculture Rice Research and Extension Center (RREC) near Stuttgart, Ark., and has been released to qualified seed growers for the 2014 growing season. LaKast has very high rough rice grain yield, good milling yield and earliness. It is similar in maturity to Antonio and 5 to 7 days earlier than Roy J. It is similar in height to Roy J and has straw strength similar to Francis and Wells. LaKast was developed with the use of rice grower check-off funds distributed by the Arkansas Rice Research and Promotion Board.

PROCEDURES

LaKast rice (*Oryza sativa* L.), is a very high yielding, very short season, long-grain rice cultivar developed by the Arkansas Agricultural Experiment Station. LaKast originated from the cross LaGrue//Katy/Starbonnet/3/LaGrue (cross no. 20001653), made at the Rice Research and Extension Center near Stuttgart, Ark., in 2000. The name for LaKast is derived from the first two letters of LaGrue, Katy, and Starbonnet. LaGrue is a high yielding long-grain rice described by Moldenhauer et al. (1994). Katy (Moldenhauer et al., 1990) is a blast resistant cultivar, and Starbonnet (Johnston et al., 1968) is a long-grain cultivar. LaKast had the experimental designation of RU0801081. The experimental designation for early evaluation of LaKast was STG04L-18-043, starting with a bulk of F_6 seed from the 2004 panicle row L-18-043. LaKast was tested in the Arkansas Rice Performance Trials (ARPT) and the Cooperative Uniform Regional Rice Nursery (URRN) during 2008-2013 as entry RU0801081 (RU number indicated Cooperative Uniform Regional Rice Nursery; 08 indicates year entered was 2008; 01 indicates Stuttgart, Ark.; and 081 its entry number).

In 2010, the ARPT was conducted at six locations in Arkansas: Rice Research and Extension Center (RREC), near Stuttgart, Ark.; Newport Extension Center (NEC), Newport, Ark.; Northeast Research and Extension Center, (NEREC), Keiser, Ark.; Pine Tree Research Station, (PTRS), near Colt, Ark.; a Clay County producer field (CCPF), Corning, Ark.; and a Lonoke County producer field (LCPF), Lonoke, Ark. In 2011, the tests were conducted at the CCPF, NEC, and PTRS; in 2012, the trials were grown at RREC, NEC, NEREC, PTRS, and CCPF. In 2013, the ARPT was grown at the RREC, NEC, NEREC, PTRS, CCPF, and a Desha County producer field (DCPF), Desha County, Ark. From 2010 to 2012, the tests had three replications per location to reduce soil heterogeneity effects and to decrease the amount of experimental error. In 2013, the ARPT was increased to four replications per location. LaKast was also grown in the advanced group of the URRN at RREC; Malden, Missouri; Crowley, Louisiana; Stoneville, Mississippi; and Beaumont, Texas from 2010 to 2013. This test has three replications per location. Data collected from these tests included plant height, maturity, lodging, kernel weight, percent head rice, percent total rice, grain yield adjusted to 12% moisture, and disease reaction information. Cultural practices varied somewhat among locations, but overall the trials were grown under conditions of high productivity as recommended by the University of Arkansas System Division of Agriculture's Cooperative Extension Service Rice Production Handbook MP192 (CES, 2001). Agronomic and milling data are presented in Tables 1 and 2. Disease ratings, which are indications of potential damage under conditions favorable for development of specific diseases, have been reported on a scale from 0 = least susceptible to 9 = most susceptible, or as VS, S, MS, MR, and R for very susceptible, susceptible, moderately susceptible, moderately resistant, and resistant, respectively. Straw strength is a relative estimate based on observations of lodging in field tests using the scale from 0 = very strong straw to 9 = very weak straw, totally lodged.

RESULTS AND DISCUSSION

Rough rice grain yields of LaKast have consistently ranked as one of the highest in the Arkansas Rice Performance Trials (ARPT). In 20 ARPT tests (2010 to 2013), LaKast, Roy J, Taggart, Francis, Wells, Templeton, and Cheniere averaged yields of 198, 203, 198, 197, 187, 171, and 176 bu/acre, respectively (Table 1). Data from the URRN (Table 2), 2010 to 2013, showed that LaKast average grain yield of 202 bu/acre compared favorably with those of Roy J, Taggart, Templeton, Francis, Wells, Mermentau, and Cheniere, at 189, 192, 183, 174, 172, 191, and 179 bu/acre, respectively. Milling yields (mg/g whole kernel:mg/g total milled rice) at 120 mg/g moisture from the ARPT, 2010 to 2013, averaged 600:700, 610:700, 590:710, 590:700, 620:710, 580:720, and 620:700, for Lakast, Roy J, Taggart, Templeton, Francis, Wells, and Cheniere, respectively (Table 1). Milling yields for the URRN in Arkansas, 2011 to 2013, averaged 570:710, 590:700, 570:700, 560:700, 540:700, 540:710, and 630:720, for LaKast, Roy J, Taggart, Templeton, Francis, Wells, and Cheniere, respectively

LaKast is a very short season variety similar in maturity to CL111 which is 5 to 7 days earlier than Roy J. LaKast has straw strength similar to Francis or Wells which is an indicator of lodging resistance. On a relative straw strength scale (0 = very strong straw, 9 = very weak straw), LaKast, Francis, Wells, LaGrue, Cocodrie, and Roy J rated 4, 4, 3, 5, 2, and 1, respectively. LaKast is approximately 42 inches in plant height which is similar to Roy J.

Disease ratings for LaKast are listed in Table 3. Lakast, like Francis, and LaGrue, is susceptible (S) to common rice blast [*Pyricularia grisea* (Cooke) Sacc.] races IB-1, IB-33, IB-49, IC-17, IE-1, and IE-1K with summary ratings in greenhouse tests of 4, 6, 6, 4, 5, and 4, respectively, using the standard disease scale of 0 = immune, 9 = maximum disease susceptibility. LaKast is rated S to sheath blight (*Rhizoctonia solani* Kühn) which compares with Francis (MS), Wells (S), Cheniere (S), Taggart (MS), and Cocodrie (S), using the standard disease R = resistant, MR = moderately resistant, MS = moderately susceptible, S = susceptible and VS = very susceptible to disease. LaKast is rated S for kernel smut [*Tilletia barclayana* (Bref.) Sacc. & Syd. in Sacc.] which compares to Francis (VS), Wells (S), LaGrue (VS), Mermentau (S), and Cocodrie (S).

LaKast is rated S to stem rot, S to narrow brown leaf spot (*Cercospora oryzae* Miyake), and S to false smut [*Ustilaginoidea virens* (Cooke) Takah]. Like LaGrue, it is MS to crown (black) sheath rot. LaKast is rated S to bacterial panicle blight (*Burkholderia glumae*). LaKast has a MS reaction to the physiological disorder straighthead.

Plants of LaKast have erect culms, green erect leaves, and glabrous lemma, palea, and leaf blades. The lemma and palea are straw colored with red and purple apiculi, many of which fade to straw at maturity. Kernels of LaKast are long at 7.60 mm compared to Roy J, Wells, and Taggart at 7.22, 7.25, and 7.48 mm, respectively. Individual milled kernel weights of LaKast, Roy J, Taggart, Templeton, Francis, Wells, and Cheniere averaged 21.9, 20.7, 22.8, 19.0, 18.9, 20.9, and 19.0 mg/kernel, respectively, in the ARPT 2009-2012 in data from the Riceland Quality Laboratory.

The endosperm of LaKast is nonglutinous, nonaromatic, and covered by a light brown pericarp. Rice quality parameters indicate that Lakast has typical southern U.S. long-grain rice cooking quality characteristics as described by Webb et al. (1985). LaKast has an average apparent starch amylose content of 22.0 g/kg and an intermediate gelatinization temperature (70 °C to 75 °C), as indicated by an average alkali (17 g/kg KOH) spreading reaction of 3 to 5.

SIGNIFICANCE OF FINDINGS

The release of LaKast provides producers with a high yielding, very short season, long-grain rice replacement for Wells or Francis. It has the added benefit of yield stability over time, yielding well in either hot or cool years.

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Table 1. Four-year average for yield and three-year average for the agronomic data from the 2010 to 2013 Arkansas Rice Performance Trials for LaKast and other cultivars.

Cultivar	Grain type[a]	Yield[b] 2010	2011	2012	2013	Mean	Height[c]	50% Heading[d]	Chalky kernels[e]	Milling[f]
		----------	----------	(bu/acre)	----------	----------	(inches)	(days)		(HR:TOT)
LaKast	L	194	190	210	197	198	42	79	0.82	60:70
Francis	L	184	195	213	196	197	40	81	1.03	62:71
Wells	L	170	182	205	191	187	41	81	0.95	58:72
Taggart	L	180	215	199	199	198	44	84	0.69	59:71
Roy J	L	179	196	234	203	203	42	85	0.68	61:70
Templeton	L	161	166	186	-	171	46	88	0.58	59:70
Cheniere	L	158	177	192	-	176	38	86	0.87	62:70

[a] Grain type L = long-grain.

[b] Yield trials in 2010 consisted of seven locations, Rice Research and Extension Center (RREC), near Stuttgart, Ark.; Pine Tree Research Station (PTRS), near Colt, Ark.; Southeast Branch Experiment Station (SEBES), Rowher, Ark.; Northeast Research and Extension Center (NEREC), Keiser, Ark.; Lonoke County Farmer Field (LC), Lonoke, Ark.; Newport Extension Center (NEC), Newport, and Clay County Farmer Field, (CC), Corning, Ark.; in 2011 the successful trials were grown at CC, NEC, and PTRS; in 2012 the trials were at RREC, PTRS, NEREC, NEC, and CC; and in 2013 trials were at CC, Desha County Farmer Field (DC), NEREC, NEC, PTRS, and RREC.

[c] Height data is from 2011 to 2013.

[d] Heading information from 2011 to 2013.

[e] Data for chalk is from 2011 to 2012 Riceland Grain Quality Laboratory data.

[f] Milling figures are head rice:total milled rice 2011 to 2013, 2011 data from Riceland Grain Quality Laboratory.

Table 2. Data from the 2010 to 2013 Uniform Regional Rice Nursery for LaKast and other check cultivars. No data from Arkansas in 2010.

Cultivar	Yield[a] 2010	2011	2012	2013	Mean	Height[b]	50% Heading[c]	Kernel weight[d]	Milling[e]
	(bu/acre)					(inches)	(days)	(mg)	(HR:TOT)
LaKast	195	179	215	218	202	43	87	18.3	57:71
Wells	151	156	181	199	172	42	89	18.2	54:71
Francis	161	149	189	195	174	41	88	15.7	54:70
Taggart	164	191	202	211	192	45	91	18.9	57:70
Roy J	180	170	190	215	189	42	93	17.2	59:70
Mermentau	175	174	213	201	191	40	89	16.4	64:70
Templeton	161	173	192	207	183	41	91	16.2	56:70
Cheniere	169	166	186	196	179	38	88	15.9	63:72

[a] AR = Rice Research and Extension Center, Stuttgart, Ark.; LA = Rice Research Station Crowley, La.; MO = Malden, Mo.; MS = Stoneville, Miss.; and TX = Texas A&M, Beaumont, Texas.

[b] Height data from Arkansas 2011 to 2013 only.

[c] Heading data from Arkansas 2011 to 2013 only.

[d] Kernel weight data is only collected in Arkansas on milled rice.

[e] Milling figures are % head rice:% total milled rice.

Table 3. Rice variety reactions[a] to diseases (2013).

Cultivar	Sheath blight	Blast	Straight-head	Bacterial panicle blight	Narrow brown leaf spot	Stem rot	Kernel smut	False smut	Lodging	Black sheath rot	Sheath spot
Antonio	S	S		MS		S	S	MS	MS		
LaKast	S	S	MS	S	S	S	S	S	MS	MS	S
Bengal	MS	S	VS	VS	S	VS	MS	MS	MR	MR	
Caffey	MS			S	R			MS			
Cheniere	S	VS	VS	VS	S	S	S	S	MR	MS	
CL111	VS	MS	S	VS	VS	VS	S	S	MS	S	
CL142-AR	MS	S	MS	S	S	S	S	S	S	S	

continued

Table 3. Continued.

Cultivar	Sheath blight	Blast	Straight-head	Bacterial panicle blight	Narrow brown leaf spot	Stem rot	Kernel smut	False smut	Lodging	Black sheath rot	Sheath spot
CL 151	S	VS	VS	VS	S	VS	S	S	MR	S	
CL 152	S	VS	S	S	R		VS	S			
CL 162	VS	VS		VS	R		S	S	S		
CL 261	MS	VS	S	VS	S	VS	MS	S	MS	MS	
Cocodrie	S	S	VS	S	S	VS	S	S	MR	S	
Colorado	S	VS		S				S			
Francis	MS	VS	MR	VS	S	S	VS	S	MS	S	
Jazzman	MS	S	S	MS	S	S	MS	S	MS	MS	
Jazzman-2	VS	S		VS	MR		S	S			
JES	S	R	VS	S	R	VS	MS	MS	S	MR	
Jupiter	S	S	S	MR	MS	VS	MS	MS	MS	MR	
Mermentau	S	S	VS	MS			S	S	MS		
Rex	S	S	S	S	MS	S	S	S	MR	S	
Roy J	MS	S	S	S	MR	S	VS	S	MR	MS	
RiceTec CLXL729	MS	R	MS	MR	MS	S	MS	S	S	S	
RiceTec CL XL745	S	R	R	MR	MS	S	MS	S	S	S	S
RiceTec CL XP756	MS							S		S	
RiceTec XL723	MS	R	S	MR	MS	S	MS	S	MS	S	
RiceTec XL753	MS			MR			MS	S		S	
RiceTec XP754	MS							S		S	S
Taggart	MS	MS	R	MS	MS	S	S	S	MS	MS	
Templeton	MS	R	S	MS	S	MS	S	S	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. Reactions were determined based on historical and recent observations from test plots and in grower fields across Arkansas. In general, these reactions would be expected under conditions that favor severe disease development including excessive nitrogen rates (most diseases) or low flood depth (blast).

Table prepared by Y. Wamishe, /Extension Plant Pathologist and R.D. Cartwright, Associate Director - Ag and Natural Resources.

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 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, earliness, erect leaves), and superior grain quality (i.e., 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 pure line rice breeding effort at the University of Arkansas.

INTRODUCTION

The rice breeding and genetics program at the University of Arkansas System Division of Agriculture Rice Research and Extension Center (RREC) near 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 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. Information is compiled from all the disciplines to make selections that are relevant to the needs of the rice industry. We are always looking for ways to enable producers to become more economically viable and to add value to their product. Breeding objectives shift over time to accommodate the demands of these players.

Primary breeding objectives for improved long-grain and medium-grain cultivars include: standard cooking quality, excellent grain and milling yields, improved plant type, and pest resistance. Through the years, improved disease resistance for rice blast and sheath blight has been a major goal. Blast [*Pyricularia grisea* (Cooke) Sacc.] resistance has been addressed through research by the pathology team, visiting scholars, graduate students, and through the development and release of the cultivars Katy, Kaybonnet, Drew, Ahrent, and Templeton. Banks was also the result of the initiative to develop blast-resistant Arkansas cultivars, 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, the most recently released blast-resistant cultivar has resistance to the race *IE-1k*. Many of the experimental lines within the program retain the gene *Pi-ta* which provides resistance to most southern blast ecotypes. Sheath blight (*Rhizoctonia solani* Kühn) tolerance also 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 characteristic 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, and Roy J and LaKast.

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, CIAT, IRRI, and the Africa Rice Center (AfricaRice). Crosses are made yearly to improve grain yield and to incorporate genes for broad-based disease resistance, improved plant type (i.e., short-stature, earliness, erect leaves), superior quality (i.e., 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 and increase seed for early generation selections each year. Selected lines are evaluated extensively for yield, milling, cooking characteristics (Riceland Foods Inc. laboratory), 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 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. Every year the Arkansas Rice Performance Trials (ARPT) are conducted by the Arkansas Rice Extension Specialist. They include current rice cultivars and promising new lines developed in the Arkansas program and from cooperating programs in the other southern rice-producing states. The most advanced lines are also included in the Uniform Regional Rice Nursery (URRN) grown in Arkansas, Louisianna, Mississippi, Missouri, and Texas. These trials provide substantial data to facilitate the selection of materials for future release and to provide producers with current information on rice cultivar performance. Disease data are collected from ongoing inoculated disease plots for sheath blight and blast, general observation tests planted in fields with historically high incidences of disease, and observations made during the agronomic testing of entries.

RESULTS AND DISCUSSION

LaKast, which will be released to seed growers in 2014, is a high yielding, very short season, long-grain line. LaKast originated from the cross, no. 20001653 (made at the RREC in 2000), which has LaGrue, Katy, and Starbonnet in its parentage. It was highly competitive during the hot growing season of 2010, when it yielded 194 bu/acre compared to Francis and Roy J at 184 and 179 bu/acre, respectively. Subsequently, in 2011, 2012, and 2013 the yield for LaKast was 191, 210, and 197 bu/acre (Table 1), which makes it comparable with Roy J, However it reaches maturity five to seven days sooner than Roy J. LaKast and Wells have a similar kernel weight but the kernel length of LaKast is one of the longest at 7.6 mm. Head rice yield and cooking quality are also comparable to Wells and it has a clear translucent kernel with low chalk (Table 1). LaKast and Wells both have moderate lodging resistance ratings. The milling yield of LaKast in the ARPT, 2011 to 2013 (Table 1) was 61% head rice and 71% total rice. The total season N application recommendations for LaKast are 150 lb/acre. LaKast does not carry any major resistance genes and is susceptible to rice blast, similar to Roy J or Wells. It is also susceptible to bacterial panicle blight (*Burkholderia glumae*) as well as kernel smut [*Tilletia barclayana* (Bref.) Sacc. & Syd. in Sacc.] like Wells. LaKast is considered moderately susceptible to straighthead and is comparable with Catahoula or CL142-AR.

This program is also evaluating a promising Clearfield line 121102. This line has Drew, CL161, Katy, Starbonnet, a Drew sister line, Lemont, Radiated Bonnet 73, and a Francis sister line in its pedigree. 121102 was included in the URRN and ARPT for the first time in 2012 and now has two years of field data illustrating its superior lodging resistance and high yield potential relative to other modern Clearfield cultivars. In the ARPT in 2013 (Table 1), it yielded 186 bu/acre compared to CL151, CL152, CL142-AR, CL XL729, and CL XL745 at 180, 160, 186, 199, and 238 bu/acre, respectively.

This line is comparable with CL151 and CL152 in that it has semidwarf plant stature. It is also short seasoned, and carries the gene *Pi-ta* which provides resistance to the common blast races in the southern growing region. It maintains excellent grain quality with clear translucent kernels that have very little chalk. The total season N application recommendation for EXP121102 is 135 lb/acre. Additional data will be collected on this line in the ARPT, URRN, DD50, and Variety by Nitrogen Test in 2014. Potentially, foundation seed of this line may be produced in 2014, while it undergoes a final assessment for release.

Another expriemental line that displayed promising cultivar potential in the 2013 ARPT was EXP131084. This line originated from a cross between a Francis anther culture line and Roy J. This line had an exceptionally high yield in its first year of evaluation with an average overall yield of 217 bu/acre in 2013, which was a higher yield than the other experimental lines and was second only to the RiceTec hybrid XL753 which yielded 238 bu/acre (Table 2). This line is a short seasoned line that has high milling yield potential. It will continue to be examined the 2014 ARPT while it is grown in breeder head rows.

Crosses have been made for high yield, good quality, improved milling, and disease resistance in various combinations. The F_2 populations from these crosses will be evaluated in 2014 and selections will be grown in the winter nursery during the winter of 2014-2015. Currently, we have 5100 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 2014.

Marker-assisted selection continues to be an instrumental tool in modern breeding. Molecular markers have been utilized dynamically by this program to select the lines which carry genes associated with high yield in the wild species *Orzya rufipogon*, the *Pi-ta* gene for blast resistance and the CT classes to predict cooking quality (see Boyett et al., 2005 and 2009). In 2014 there are 2 lines from the *Oryza rufipogon* crosses in the ARPT. Additionally, this program is conducting research that aims 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 will improve the accuracy and efficiency by which parents are chosen for crossing and lines are advanced.

SIGNIFICANCE OF FINDINGS

The goal of the rice breeding program is to develop maximum yielding cultivars with excellent cooking, processing and milling quality and good levels of disease resistance for release to Arkansas rice producers. The release of Taggart, Templeton, Roy J, and most recently LaKast demonstrate that continued improvement in rice cultivars for the producers of Arkansas are achieved through this program. LaKast could potentially be the modern replacement for Wells. Steps towards breeding improved lines are a staple of the current and future program. New cultivars will have the characteristics of improved: disease resistance, plant type, rough rice grain and milling yields, and kernel size, and overall grain quality. Additionally, this program remains focused on releasing cultivars to meet the competitive demands of the traditional southern U.S. long- and medium-grain markets and for the specialty markets that have emerged in recent years.

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Table 1. Four-year average for yield and three-year average for the agronomic data from the 2010 to 2013 Arkansas Rice Performance Trials for LaKast and other cultivars.

Cultivar	Grain type[a]	Yield[b] 2010	2011	2012	2013	Mean[c]	Height[d]	50% Heading[e]	Chalky kernels[f]	Milling[g]
		------------------------------		(bu/acre)		------------------------------	(inches)	(days)		(HR:TOT)
LaKast	L	194	190	210	197	198	42	79	0.82	61:71
Francis	L	184	195	213	196	197	40	81	1.03	64:71
Wells	L	170	182	205	191	187	41	81	0.95	59:72
Mermentau	L	-	-	216	183	200	37	79	1.55	65:70
Taggart	L	180	215	199	199	198	44	84	0.70	60:71
Roy J	L	179	196	234	203	203	42	85	0.68	63:71
RTCLXL723	L	212	191	222	200	206	44	79	2.59	63:71
RTCLXL745	L	223-	254	246	238	240	42	78	1.67	61:71
EXP121102[h]	L	-	-	215	186	201	37	83	0.70	63:71
CL142-AR[h]	L	166	174	193	186	180	45	80	1.08	60:71
CL151	L	182	142	204	180	177	39	79	1.46	65:71
CL152	L	.	178	192	160	177	38	81	1.11	62:70
RTCLXL729	L	231	180	203	199	203	43	79	2.22	60:70

[a] Grain type L = long-grain.

[b] Yield trials in 2010 consisted of seven locations, Rice Research and Extension Center, (RREC), near Stuttgart, Ark., Pine Tree Research Station (PTRS), Colt, Ark., Southeast Branch Experiment Station (SEBES), Rowher, Ark., Northeast Research and Extension Center (NEREC), Keiser, Ark., Lonoke County Farmer Field (LC), Lonoke, Ark., Newport Extension Center (NEC), Newport, Ark., and Clay County Farmer Field (CC), Corning, Ark.; in 2011, the successful trials were grown at CC, NEC, and PTRS; in 2012, the trials were at RREC, PTRS, NEREC, NEC, and CC; and in 2013, trials were at CC, Desha County Farmer Field (DC), NEREC, NEC, PTRS, and RREC.

[c] Mean is a non-weighted average of the mean yield from each year's ARPT.

[d] Height data is from 2011 to 2013.

[e] Heading information from 2011 to 2013.

[f] Data for chalk is from 2011 to 2012 Riceland Grain Quality Laboratory data.

[g] Milling figures are head rice:total milled rice 2011 to 2013, 2011 data from Riceland Grain Quality Laboratory.

[h] EXP stands for experimental lines not for sale and CL stands for Clearfield lines.

Table 2. Data from the 2013 Arkansas Rice Performance Trials for a promising experimental line and check cultivars.

Cultivar	Grain type[a]	Yield[b] CC	DC	NEREC	NBES	PTBS	RREC	Mean	50% Height	Heading	Milling[c]
		----------	----------	----------	(bu/acre)	----------	----------	----------	(inches)	(days)	(HR:TOT)
EXP121102[d]	L	170	232	159	161	178	217	186	37	83	63:71
CL151	L	190	134	192	133	209	222	180	39	79	65:71
CL152	L	151	201	142	115	164	184	160	38	81	62:70
CL142-AR	L	170	220	170	148	191	217	186	45	80	60:71
RTCLXL729	L	178	156	205	167	237	251	199	44	79	63:71
RTCLXL745	L	156	177	143	162	217	202	176	42	78	61:71
EXP131084	L	203	251	220	171	200	255	217	40	80	62:68
LaKast	L	184	230	184	167	186	233	197	42	79	61:71
Roy J	L	200	231	204	169	182	233	203	42	85	63:71
Wells	L	198	221	175	165	174	213	191	41	81	59:72
RTXL753	L	250	256	231	202	238	252	238	43	79	60:70

[a] Grain type L = long-grain.

[b] Yield trials in 2013 consisted of five locations, Rice Research and Extension Center (RREC), near Stuttgart, Ark., Pine Tree Research Station (PTRS), Colt, Ark., Northeast Research and Extension Center (NEREC), Keiser, Ark., and Newport Extension Center (NEC), Newport, Ark.; Clay County Farmer Field (CC), Corning, Ark., and Desha County Farmer Field (DC).

[c] Milling figures are head rice:total milled rice.

[d] EXP stands for experimental lines not for sale, CL stands for Clearfield lines, and RT stands for RiceTec.

BREEDING, GENETICS, AND PHYSIOLOGY

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 of the program, maximum mechanized-operation, multiple generations per year in the winter nursery, and new technologies such as molecular marker-assisted selection (MAS) will also be rigorously pursued.

INTRODUCTION

Medium-grain rice is the important component of Arkansas rice. Arkansas ranks second in medium-grain rice production in the United States only behind California. During 2002 to 2012, an average of 0.16 million acres of medium-grain rice was grown annually, which makes up about 11% of total state rice acreage (USDA-ERS, 2013). 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 Arkansas) to a low of 99,000 acres in 2008 (7% of total rice planted in Arkansas).

A significant portion of Arkansas rice area was planted to semi-dwarf long-grain varieties, such as CL151, CL131, CL111, and Cheniere. However, locally developed 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. Rice breeding efforts will continue because genetic potential still exists for further improvement of current varieties.

The inter-subspecies hybrids between *indica* male sterile lines and tropical *japonica* restorer/pollinator lines that were first commercialized in the United States in 1999 by RiceTec have a great yield advantage over conventional pure-line varieties (Walton, 2003). However, the further expansion of hybrid rice may be constrained by its inconsistent milling yield, poor grain quality, lodging susceptibility, seed shattering, and high seed cost. A public hybrid rice research program that focuses on the development of adapted lines (male-sterile, maintainer, and restorer lines) will be instrumental to overcome such constraints.

PROCEDURES

Potential parents for the breeding program are evaluated for the desired traits. Cross combinations are programmed that combine desired characteristics to fulfill the breeding objectives. Marker-assisted selection (MAS) 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 Rice Research and Extension Center (RREC) near Stuttgart, Ark., and the winter nursery in Lajas, Puerto Rico. The 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. Test tube milling, as well as the physicochemical analysis at the USDA Rice Quality Lab at Dale Bumpers National Rice Research Center, will be conducted to eliminate lines with evident quality problems and/or maintain standard U.S. rice quality of different grain types. Yield evaluations include the Stuttgart Initial Test (SIT) and Clearfield SIT (CSIT) at RREC near Stuttgart, Ark.; the Advanced Yield trial (AYT) at RREC, Pine Tree Research Station (PTRS) near Colt, Ark., and Rohwer Research Station (RRS); the Arkansas Rice Performance Trials (ARPT) carried out 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 Louisiana, Mississippi, Missouri, and Texas. Selected F_2 segregating populations will be evaluated at PTRS under high natural disease pressure using blast spreader rows. Promising advanced lines will be provided to cooperating projects for further evaluation of the susceptibility to the physiological disorder straighthead and resistance to sheath blight, blast, and panicle blight, grain and cooking/processing quality, and nitrogen (N) 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

During the transition of this project, a number of breeding populations of different stages were maintained by Karen Moldenhauer. Selection and advancement of those materials was continued in 2013. New populations were created and rapidly advanced, which included 682 transplanted F_1 populations, 302 space-planted F_2 populations, and 17,800 panicle rows ranging from F_3 to F_5. A total of 531 transplanted F_1 populations were selected and bulk-harvested for planting of F_2 populations in 2014. Visual selection on 302 space-planted F_2 populations resulted in a total of 15,000 panicles, which will be grown as F_3 panicle rows in 2014. Out of 17,800 panicle rows, 1,380 rows were selected for advancement to the next generation, while 775 rows appeared to be uniform and superior to others, therefore were bulk-harvested as candidates of 2014 SIT or CSIT trials. A total of 133 lines (56 medium-grain, 54 conventional, and 23 Clearfield long-grain lines) have been tested in both the Stuttgart Initial Trial (SIT) and/or Pine Tree preliminary trial. Several of them showed the yield potential similar to or better than the check varieties (Tables 1-3). Eight advanced medium-grain lines were evaluated in ARPT and seven of them were also included in URRN. Results of those entries and selected check varieties are listed in Table 4. Two Puerto Rico winter nurseries of 9,000 panicle rows were planted in early August and early October, respectively, and the first nursery was harvested and turned around in early December. A total of 736 new crosses were made throughout 2013, which included 299 medium-grain, 405 long-grain, and 32 aromatic crosses.

Two advanced conventional medium-grain lines, 13AR1021 (RU1301021) and 13AR1130 (RU1301130), continued showing excellent yield potential, good milling, and superior grain quality in 2013. Two consecutive purifications and increases were conducted in Puerto Rico and Stuttgart, Ark. A number of semi-dwarf and early-maturing conventional medium- and long-grain lines, as well as Clearfield lines that possess great yield potential, and good milling and grain quality were also identified from SIT trials, and will be advanced to 2014 URRN and ARPT tests.

SIGNIFICANCE OF FINDINGS

Successful development of medium-grain and semi-dwarf long-grain rice varieties offer 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 conventional long-grain experimental lines and check varieties in Stuttgart Initial Trial (SIT) at Rice Research and Extension Center near Stuttgart, Ark., 2013.

Variety/line	Pedigree	Seedling vigor[a]	Days to 50% heading	Plant height	Yield	Milling yield	
						Head rice	Total rice
				(cm)	(bu/acre)	----------- (%)	------------
13SIT2008	STG05F5-08-104/CHNR//STG05P-26-096	3.0	71	111	234	62.4	71.7
13SIT2012	STG05F5-08-104/CHNR//STG05P-26-096	3.0	69	110	234	65.5	72.0
13SIT2013	STG05F5-08-104/CHNR//STG05P-26-096	3.0	69	103	237	64.1	71.3
13SIT2014	STG05F5-08-104/CHNR//STG05P-26-096	3.5	70	105	243	67.0	72.0
13SIT2035	STG05F5-08-104/STG03F5-09-076//STG05P-26-096	4.0	70	106	228	66.2	71.7
13SIT2037	STG05F5-08-104/STG03F5-09-076//STG05P-26-096	3.0	70	109	238	65.3	72.0
13SIT2039	STG05F5-08-104/STG03F5-09-076//STG05P-26-096	3.0	70	105	234	67.0	72.2
13SIT2040	STG05F5-08-104/STG03F5-09-076//STG05P-26-096	3.5	70	108	235	64.1	72.1
13SIT2041	STG05F5-08-104/STG03F5-09-076//STG05P-26-096	3.0	71	110	233	66.4	71.2
08AR1081	RU0801081	3.0	70	112	247	66.0	72.4
Cheniere	Cheniere	3.0	75	103	230	71.1	74.3
CL151	CL151	3.0	72	106	244	69.4	72.5
Mermentau	Mermentau	3.0	72	102	243	68.7	72.2
Roy J	Roy J	3.0	78	117	238	69.3	73.5
Wells	Wells	3.0	72	110	238	66.3	73.0

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

Table 2. Performance of selected conventional medium-grain experimental lines and check varieties in Stuttgart Initial Trial (SIT) at Rice Research and Extension Center near Stuttgart, Ark., 2013.

Variety/line	Pedigree	Seedling vigor[a]	Days to 50% heading	Plant height	Yield	Milling yield Head rice	Milling yield Total rice
				(cm)	(bu/acre)	-------------- (%)	------------
13SIT2078	M207/JPTR//JPTR	3.5	75	106	230	65.0	67.6
13SIT2089	M206/STG99F5-07-118//JPTR	3.5	69	108	238	64.4	71.0
13SIT2097	STG09PR-89-082/JPTR	3.5	66	117	222	66.7	70.9
13SIT2100	STG09PR-89-082/JPTR	3.5	67	113	227	67.0	71.7
13SIT2104	STG09PR-89-082/JPTR	3.0	78	118	221	69.2	71.1
13SIT2106	JPTR/RU1001102	3.0	73	101	232	59.8	68.1
13SIT2107	JPTR/RU1001102	3.0	72	116	228	62.7	69.1
13SIT2110	JPTR/RU1001102	3.5	73	102	233	63.1	68.2
13SIT2111	JPTR/RU1001102	3.0	70	106	228	62.4	68.3
13SIT2115	JPTR/RU1001102	3.0	73	105	226	62.8	69.1
13SIT2116	JPTR/RU1001102	3.5	74	100	222	64.1	68.8
13SIT2117	JPTR/RU1001102	3.5	75	105	231	62.0	67.9
13SIT2118	JPTR/RU1001102	3.5	73	104	230	64.5	68.9
Jupiter	Jupiter	3.5	74	104	240	68.3	69.7
Caffey	Caffey	3.0	73	103	240	69.4	72.5

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

Table 3. Performance of selected Clearfield long-grain experimental lines and check varieties in Clearfield Stuttgart Initial Trial (CSIT) at Rice Research and Extension Center near Stuttgart, Ark., 2013.

Variety/line	Pedigree	Seedling vigor[a]	Days to 50% heading	Plant height	Yield	Milling yield	
						Head rice	Total rice
				(cm)	(bu/acre)	-------------- (%)	------------
13CLSIT2002	CCDR//CCDR/JEFF/3/CL131	3.0	75	99	205	64.9	70.3
13CLSIT2003	CCDR//CCDR/JEFF/3/CL131	3.0	76	101	209	67.0	71.7
13CLSIT2005	CCDR//CCDR/JEFF/3/CL131	3.5	78	97	205	69.1	72.8
13CLSIT2006	CCDR//CCDR/JEFF/3/CL131	3.5	74	97	203	64.5	69.9
13CLSIT2007	CCDR//CCDR/JEFF/3/CL131	3.5	74	102	215	66.7	71.1
13CLSIT2009	RU0902125/CL131	3.0	79	100	206	66.5	69.2
13CLSIT2012	RU0902125/CL131	3.0	77	98	209	65.2	69.7
13CLSIT2020	CCDR//CCDR/JEFF/3/CL131	3.0	76	98	204	64.1	69.0
13CLSIT2022	RU0902125/CL131	3.0	77	95	210	67.2	71.9
13CLSIT2023	RU0902125/CL131	3.0	76	98	217	69.0	72.3
13CLSIT2024	RU0902125/CL131	3.0	79	101	213	68.7	72.7
CL111	CL111	3.0	76	103	211	65.5	70.6
CL142	CL142	3.5	77	113	178	63.7	70.2
CL151	CL151	3.0	74	98	200	66.9	71.4
CL152	CL152	3.0	81	99	194	64.8	69.2

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

Table 4. Average yield, milling, and agronomic characteristics of 8 experimental medium-grain lines and 2 check varieties tested at 6 Arkansas locations, 2013.

Entry	RU	Pedigree	Days to 50% heading	Plant height	Yield	Milling yields	
						Head rice	Total rice
				(cm)	(bu/acre)	---------- (%) ----------	
13ARPT268	RU1301121	M206/STG03AC-25-109//RU0401127	75	95	194	64.6	68.7
13ARPT269	RU1301021	M206//BNGL/LFTE/3/JPTR	76	96	202	56.7	66.5
13ARPT270	RU1301030	M206/STG02PR-01-109//JPTR	76	93	197	57.3	67.1
13ARPT271		JPTR/RU0401136//STG05AC-05-029	75	90	175	57.9	67.6
13ARPT272	RU1301124	STG02P-02-072/RU0502137//STG03F5-04-002	77	103	181	52.5	66.5
13ARPT273	RU1301027	JPTR/RU0401136//STG05AC-05-029	77	93	187	53.0	66.1
13ARPT274	RU1301130	M206/STG03AC-21-047//JPTR	81	101	202	59.1	66.6
13ARPT275	RU1301133	M206/STG03AC-25-109//RU0401127	74	95	176	63.7	68.3
13ARPT209		Caffey	80	96	203	58.3	67.0
13ARPT210		Jupiter	82	96	194	60.6	65.7

Rice Breeding and Pathology Technical Support Program

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ABSTRACT

Development of disease-resistant rice is one of the most important achievements rice breeders attempt to accomplish at the University of Arkansas System Division of Agriculture Rice Research and Extension Center (RREC) near Stuttgart, Ark. The center's plant pathology group assists with this goal by screening entries as potential new lines in the greenhouse and field. Blast [*Magnaportha grisea* (T.T. Herbert) M.E. Barr], sheath blight, (*Rhizoctonia solani* Kuhn), and bacterial panicle blight [*Burkholderia glumae* (Kurita and Tabei)] are diseases currently being screened at the RREC. Artificial inoculation of these pathogens on rice is key to collecting disease severity data. Disease inocula are prepared in the laboratory and applied to the plants using specific protocols. Blast screening is conducted both in the greenhouse and the field. Sheath blight and bacterial panicle blight are screened only in the field. Data from these tests are used by the breeding program either to transfer genes for resistance into adapted and high yielding varieties or to advance entries to the next generation for further agronomic testing.

INTRODUCTION

Breeding for disease resistance is the major area of emphasis in any breeding program. At the Rice Research and Extension Center (RREC), rice breeders and pathologists work together to develop varieties with desirable agronomic traits and disease resistance. Released rice cultivars are also evaluated every year for disease resistance due to concerns with the evolution of new pathogen races. Disease evaluation of crops against major diseases starting in early generations has been important and is a required activity for a successful breeding program. Lines with good yield, quality, or disease resistance, which require further improvement for one or more traits can be utilized by the breeding program as parents. Rice blast and sheath blight still remain as the major diseases of rice and can result in a significant yield loss under favorable environments unless they are managed properly. Bacterial panicle blight, once considered minor and sporadic, is emerging as a challenging disease for southern rice-producing states in the U.S. This disease requires answers for several unknowns related to the bacterial complexity, host-pathogen interactions, and disease spread. Such a disease with several unknowns requires a group of skilled colleagues along with laboratory, greenhouse, and field efforts to quickly develop sound management strategies.

The screening methodology for each of the three diseases allows the rice entry to be categorized as resistant, moderately resistant, moderately susceptible, susceptible, or very susceptible. Screening for disease resistance under natural conditions may not be as reliable as with artificial inoculation. Creating a favorable environment for disease development is essential and must be done for each disease separately.

Leaf blast screening is more successful at a seedling stage in the greenhouse than in the field. However, screening for panicle blast requires more mature plants which are easier to maintain in the field. Care needs to be taken since blast disease epidemic requires tighter control on the environmental conditions the plants receive at pre- and post-inoculation. Field testing requires repeated inoculation; therefore, sizable amounts of inocula must be produced months in advance of application to the plants. Blast inoculum can suffer from contamination unless it is prepared by someone skilled with aseptic techniques. Field sheath blight inoculation also requires massive amounts of inoculum that takes months of careful preparation. Inoculum production for bacterial panicle blight requires careful handling of agar plates to obtain sizable volumes of a bacterial suspension which is backpack-sprayed onto plants between boot-split and flowering stage of the test rice lines. Within the pathology group, skilled assistants/associates train new employees and hourly workers to allow flexibility and to save costs with media preparation, inoculum production, disease rating, and maintenance of a clean laboratory environment to culture bacteria and fungi.

PROCEDURES

For greenhouse testing of blast, seven-day old blast isolates were washed from agar plates with a xanthan gum suspension to create a standardized spore suspension of 2.0×10^4 spores/ml. This suspension consisted of six blast races either applied to the plant individually or in bulk depending on the goals of the test. The 4-lf (leaf) stage plants (approximately 21 days) were sprayed directly using an airbrush tool and placed in a dew chamber for approximately 14 hours. Disease data were collected seven to ten days after the plants were removed from the dew chamber and placed on a greenhouse bench. One comprehensive greenhouse test for blast requires approximately 28 days to complete. Over 300 entries of the URRN, ARPT, and advanced lines were tested and evaluated using individual races and over 1,400 panicle row entries were screened with a bulk spore suspension in 2013.

Field testing for blast and sheath blight was replicated four times. Inoculum for blast and sheath blight consisted of sterilizing several hundred gallons of cracked corn

(corn chops) and ryegrass seed. The sterilization protocol required three days to process approximately 16 gallons of sheath blight and approximately 12 gallons of blast. The cultures were grown on a specific medium for seven days and then mixed into a sterile chops/ryegrass mixture. Sterility was maintained throughout the entire process to avoid contamination. After a week of incubation at room temperature, the fungal infected seed media was air dried in paper bags. Field tests for blast were established at the RREC and Pine Tree Research Station (PTRS) as hill plots surrounded by a spreader mixture of blast susceptible lines to encourage disease spread. Plants at tillering and heading were inoculated with dried seed media which contained up to six races of the pathogen. Plants were inoculated twice for leaf blast and at least twice for panicle blast. In the testing of sheath blight, a single hill plot nursery was utilized to evaluate sheath blight susceptibility. Air dried inoculum that contained multiple isolates of the pathogen was applied to plants at the panicle initiation growth stage.

Field testing for bacterial panicle blight was replicated four times. Two hundred ninety single row entries of 2013 URRN/ ARPT were sprayed with a bacterial suspension (approximately 1.3×10^8 cfu/ml) directly on the plants between boot-split to flowering stage. Disease data were collected from all inoculated plots using a rating scale of 0 to 9 where 0 equaled no disease and 9 equaled severe disease levels.

In addition to the disease screening of germplasm for rice breeders, the pathology technical group provided help in applied research for extension plant pathology using laboratory, greenhouse, and field resources. Greenhouse disease evaluation included mostly preliminary studies on various methods to artificially inoculate plants at both the seedling and adult developmental stage. Tested techniques included direct seed dip, foliar spray, syringe injection of culm, or a cut leaf dip. Preliminary testing for hydrogen sulfide toxicity was conducted using 11 varieties to test symptom development under greenhouse conditions. Studies were also carried out to test the activity of the commercially available fungicides to sheath blight and for possible detection of fungicide insensitivity. Investigations also continued to determine the effects of water stress, fertility levels, seeding rate, and planting dates on bacterial panicle blight incidence and severity under field conditions. Moreover, three tests on bacterial panicle blight, three on sheath blight, and one on early-season seedling diseases were conducted in collaboration with industries. The sheath blight inoculum amounted 24,960 grams to meet the needs of industry tests and 69,120 grams to meet interdepartmental collaborative activities on N-ST*R by fungicide study.

Disease data were collected from inoculated disease plots and the data were entered in the computer and summarized for each test as the protocol required.

RESULTS AND DISCUSSION

Field assessment of sheath blight, panicle blast, and bacterial panicle blight for rice entries across all tests was completed. A total of 16,512 hill plots were established to include all lines replicated, inoculated, and evaluated for leaf and panicle blast. The total number of all lines replicated, inoculated, and evaluated for sheath blight was

8,256 hill plots. As expected there was a low number of candidates scoring resistant or moderately resistant (Table 1). Surprisingly two entries (RU1201179 and RU1301176) matched the criterion for resistance to all three diseases tested. Both entries need to be followed up with further disease testing to confirm these encouraging results.

Greenhouse leaf blast evaluations were assessed for 1,058 experimental lines. These lines included 100 entries for the ARPT, 200 entries for the URRN, 64 entries for the RREC hybrid breeding program, 44 entries for the ARPT-IMI test, 30 advanced lines, and 624 selected panicle rows. With three replications the total number of evaluations for leaf blast in the greenhouse in 2013 was 9,684.

Field blast and sheath blight evaluations were assessed for 2,064 experimental lines and checks. These lines include 100 entries for the ARPT, 200 entries for the URRN, 14 entries for the RREC hybrid breeding program, 44 entries for the ARPT-IMI test, 70 entries for Missouri, 330 entries for the SIT-IMI, 220 entries for the SIT, 1,081 preliminary entries and five long-grain advanced line entries.

Greenhouse support was also provided for the entomology program by growing and maintaining inoculated plants and non-inoculated plants to be used for the stink bug transmission of bacterial panicle blight study. Technical support was provided for all extension pathology applied research, chemical industry tests, and the N-ST*R by fungicide collaborative study. Collected data from all tests were provided to the respective rice breeders, pathology extension specialist, chemical industries, and collaborators to be used as needed.

SIGNIFICANCE OF FINDINGS

The goal of the rice breeding pathology technical support program is to provide support towards increasing the efficiency of rice breeders in developing maximum yielding cultivars along with good levels of disease resistance. The other goal is to provide support to the extension plant pathologist with applied research on disease management studies. Since diseases are major problems for crop production, a rigorous support group is vital to combat major prevailing and newly emerging diseases. Every season is different with its disease problems and there is extensive work in the rice disease area that needs immense attention and a dedicated team of skilled individuals to develop cost effective solutions.

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Table 1. Number of entries that scored resistant or moderately resistant in field disease nurseries.

		Sheath blight[a]		Panicle blast[b]		Bacterial panicle blight[c]	
Test	Total entries	R	MR	R	MR	R	MR
ARPT	100	2	11	27	12	16	17
ARPT-IMI	44	0	0	7	11	na[d]	na
URRN	200	4	7	47	29	32	13
SIT	220	3	4	70	43	na	na
SIT-IMI	330	0	2	25	40	na	na
Prelim	1,081	4	35	459	93	na	na
Adv. lines	5	0	1	4	1	na	na
Hybrid	14	4	2	14	0	na	na
Missouri	70	1	3	38	1	na	na

[a] Resistant entries with an average rating score of 5 or less and no rep data scored 7 or higher. Moderately resistant entries had an average score between 5.1 and 5.5.

[b] Resistant entries with an average rating score of 4.5 or less and no rep data scored 7 or higher. Moderately resistant entries had an average score between 4.6 and 5.0.

[c] Resistant entries with an average rating score of 3 or less. Moderately resistant entries had an average score between 4 and 5.

[d] Not available.

A Preliminary Study of a White Smut Infecting Rice in Arkansas

A.C. Jecmen and D.O. TeBeest

ABSTRACT

False smut of rice is an economically important disease of rice in Arkansas. In 2011, 2012, and 2013, sori of a white smut (WS) were found in rice fields in eastern Arkansas on two rice varieties. White false smut is a disease found on rice in China and Japan. In this study, the conidia and sori from white smutted heads in Arkansas were examined, and the rDNA extracted from samples were used to determine the identity of the causal agent of the disease. Virulence tests were conducted with a WS isolate to confirm virulence to rice cultivars. Results from this study indicate the sori and spore morphology are similar to descriptions for *U. albicans*. However, sequences of rDNA amplicons indicate homology among *U. virens* and *U. albicans* isolates. The white smut isolate was virulent to two cultivars, and produced sori similar to those previously observed in the field and were similar to descriptions of *U. albicans*.

INTRODUCTION

Green false smut (GFS) of rice caused by the fungus *Ustilaginoidea virens* (Cke) Tak. [teleomorph = *Villosiclava virens* (V. Sakurai ex Nakata) E. Tanaka & C. Tanaka (Tanaka et al., 2008)] has been in the United States for many years. Green false smut in Arkansas was first reported in 1997 and the disease is now found throughout the state (Cartwright et al., 1999; Wilson et al., 2005). A white false smut of rice (WFS) was first reported in Japan and later described as a new species of *Ustilaginoidea* in China (Honkura et al., 1991; Wang and Bai, 1997). The sori and conidia of WFS on rice [Rice White Smut (RWS) in Arkansas] are white unlike GFS. In 2011, 2012 and 2013, white sori resembling WFS were found on panicles of rice cultivars Clearfield 151, Francis, and Francis, growing in fields in Jackson and St. Francis Counties in Arkansas, respectively. Each field had a recent history of GFS and was in continuous rice production for the three years. The RWS sori had morphological characters in common with the descriptions of sori of WFS by Honkura et al. (1991) and Wang and Bai (1997). Re-appearance of white sori on rice panicles in 2013 prompted this investigation to determine the causal organism. Our specific objectives were: to compare and contrast the color and morphology of sori and conidia from GFS and RWS, to investigate the ribosomal DNA sequence similarity of isolates from RWS and GFS, and to test virulence of RWS isolates to selected American rice cultivars.

MATERIALS AND METHODS

Two non-melanized white sori were found and recovered on panicles of Clearfield 151 and Francis rice (*Oryza sativa* L.) cultivars, in fields in Jackson and St. Francis Counties in Arkansas in May of 2011 and in June of 2012, respectively. In 2013, a white smut sorus was found on Francis in the same field in St. Francis County, Ark. Sori on rice panicles were photographed in the field and then taken to the laboratory for further study. Sori were observed then bisected to enable comparison of internal morphology and photographed with an Olympus E-500 8-mp camera mounted to an Olympus SZ51 stereomicroscope. Spores from GFS and RWS sori were wet mounted onto glass slides, observed and photographed with an Olympus E-500 camera fitted with an ocular micrometer to an Olympus CX31 light microscope.

Total DNA was extracted from mono-conidial isolates from GFS and RWS cultured on PDA for ribosomal DNA comparisons. Total DNA was reacted in a nested-PCR reaction with primary US1-5/US3-3 and nested primer US2-5/US4-3 sets (Zhou et al., 2003). Total DNA was also reacted in a conventional PCR reaction with ITS-1/ITS-4 universal primers (White et al., 1990). Polymerase chain reaction amplified products were resolved on 2% agarose gels containing ethidium bromide. The resolved single rDNA fragment products were purified with a ZR DNA sequencing clean-up kit (Zymo Research, Irvine, Calif.) and sequenced at the University of Arkansas DNA resources laboratory. Sequence homology was compared among GFS and RWS isolates, and to other highly similar nucleotide sequences using the Basic Local Alignment Search Tool (BLAST®, Altschul et al., 1990).

Virulence testing of a RWS isolate was performed based on the methods described by Wang et al. (2008) using 12 plants grown from Neptune and Roy J seed. Plants were grown in conducive field soil obtained from the Newport Extension Center in Newport, Ark., to maturity in 3.78-L (1-gal) pots submerged under 10 cm to 15 cm (4 inches 6 inches) of water in 18.9-L (5-gal) containers. Inoculum was prepared from cultures grown in 25 ml of wheat bran broth media (WBB) and potato dextrose broth (PDB) media for one week on a rotary shaker at 24 °C. The colony suspensions were centrifuged at 7500 rpm for 10 min, the liquid was decanted and conidia were re-suspended to a final concentration of 5.0×10^4 conidia/ml in distilled water. At the booting stage, three booted panicles selected from a total of 9 plants were inoculated with between 0.5 and 1 ml of each type of media inoculum. Six panicles from three control plants (18 total) were inoculated with water only. After inoculation, plants were placed in dew chambers at 18 °C for 48 hours, then plants were placed in 113.5-L (30-gal) opaque plastic trash bags for 120 hours at 24 °C under 10-hour day length with indirect fluorescent lighting. After the incubation period, the bags were removed and plants were moved to a greenhouse. Controls were inoculated with water and treated similarly. All plants were observed daily after inoculation. Sori that developed on panicles after emergence were counted for 33 days after inoculation.

RESULTS AND DISCUSSION

Green false smut sori are typically covered in a thin silvery membrane once they appear. This membrane ruptures revealing orange spores that later turn dark green to black at maturity. Sori of RWS are white in color after the silvery membrane ruptures and remain white after the conidia mature (Fig 1A, B). When cut in half, the outer layers of GFS sori are dark in color, then white to orange on the innermost layers while the sori of RWS remain white throughout (Fig. 2A, B). Both GFS and RWS contained remnants of stamens and pistils (Fig. 2A, C). In all years, the RWS white sori were white-to-opaque, 7.0-mm to 8.0-mm long and 4.0-mm to 6.0-mm wide. The RWS conidia were hyaline, smooth and subglobose, 4.96-µm long and 4.59-µm wide (n = 50, st. dev. 0.44 and 0.38 m, respectively). Conidia from RWS sori germinated in sterile water after 48 h at 25 °C by the formation of a translucent fusiform germ tube. The germ tube gave rise to either branching septate hyphae or phialides bearing acrogenous hyaline blastoconidia of two sizes, 1.58 µm and 3.1 µm (n = 50, st. dev. 0.39 and 0.45, respectively) at the terminus. Non-melanized and smooth conidia obtained from the sori of RWS (Fig. 2B) were not morphologically similar to melanized, warty and spined conidia of GFS (Fig. 2D).

Isolates of RWS were obtained from sori collected in 2011 and 2013 using methods developed for isolation of *U. virens*. Conidia from sori were suspended in NaOCl (0.6%) for 2 minutes, diluted sterile distilled water, and then streaked onto Petri dishes containing acidified (pH 6.0) PDA amended to contain streptomycin and ampicillin. The Petri dishes were incubated at 25 °C for two weeks. The emerged colonies were white to creamy-white when viewed from above and below, and were easy to distinguish from the dark green colonies of GFS isolates. Individual colonies were selected after two weeks of incubation on the PDA dishes and placed into 30% glycerol and stored at -80 °C in the Department of Plant Pathology, University of Arkansas.

The total DNA, extracted from green and white isolates, was reacted in a nested PCR reaction with primer sets US1-5/US3-3 and US2-5/US4-3 and by simple PCR with universal ITS-1/ITS-4 primers. Amplification products resolved in 2% agarose gels containing ethidium bromide resulted in 232 bp and 600 bp amplicons, respectively. The sequences obtained from the amplicon products were subjected to further analysis in BLASTn searches in GenBank (NCBI). The 232 bp sequences from both green and white isolates were highly consistent with UV2 and HNHS-1 sequences from *Villosiclava virens* accessions JQ828996.1 and JX427552.1 from *Ustilaginoidea virens* (Table 1).

Searches in BLASTn using the ITS1-4 amplicon sequences had a high level of homology to the 18S rRNA sequences from accession AB116645.1 of *U. virens* (Table 1).

Isolate I-9E, used in the morphology and DNA studies above, was virulent to two cultivars previously determined to be susceptible to GFS (TeBeest and Jecmen, 2013). White sori were found on panicles of Roy J and Neptune cultivars within 16 days after inoculation and incubation in a greenhouse. Thirty three days after inoculation, booted panicles inoculated with conidia suspensions from WBB cultures resulted in 31 sori on 18 Roy J panicles and 21 sori were found on 12 panicles of Neptune. Thirty three days after inoculation of 30 panicles with conidia from PDB resulted in eight sori developing; of these, one was found on Roy J and seven were found on Neptune.

This study should be considered to be a preliminary investigation of the causal agent of white smut infecting rice in Arkansas. Further study is warranted to determine the full extent of RWS in Arkansas. The discovery of RWS in 2011 is the first report of a white smut infecting rice in the USA and outside of China or Japan. Analysis of the rDNA data suggests ITS similarities to *U. albicans* and *U. virens* while the conidia and sorus morphology and coloration suggest a color and surface morphological similarity to *U. albicans*, we are compelled to reserve the name of RWS until future studies have fully investigated the taxonomy, virulence, aggressiveness, and epidemiology of RWS in Arkansas.

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Table 1. Results of BLAST® searches associated with the identification of false smut isolates *Ustilaginoidea virens* (teleomorph *Villosiclava virens*) and the white rice smut isolate *U. albicans* obtained in this study. Data compares the nucleotide sequences of amplicons obtained from two isolates of *U. virens* and one from RWS to accessions in the BLAST database using the BLASTn suite.[a]

Primers[a]	Isolate[b]	Source[c]	Top BLAST® hit[d]	E value[e]	Max identity[f]	Accession no.[g]
					(%)	
US2-5/US4-3	I-6E	CL151	*V. virens* UV2	6e-90	95	JQ828996.1
	I-7E	FRAN	*V. virens* HNHS-1	4e-110	100	JX427552.1
	I-9E	CL151	*V. virens* HNHS-1	3e-137	97	JX427552.1
ITS1/ITS4	I-6E	CL151	*V. virens* 18S	0	99	AB116645.1
	I-7E	FRAN	*V. virens* 18S	0	99	AB116645.1
	I-9E	CL151	*V. virens* 18S	0	99	AB116645.1

[a] Amplicons were obtained using primers US2-5/US4-3 and ITS1/ITS4 under conditions as described by Zhou et al. (2003) and White et al. (1990). Data presented represents forward sequences obtained from PCR reactions with the primers indicated.

[b] Ribosomal rDNA extracted from *U. virens* (teleomorph *Villosiclava virens* = (*V. virens*)) I-6E I-7E isolates and a RWS isolate, I-9E, found in Arkansas in 2011 were used to compare ITS sequence homologies.

[c] Mono-conidial isolates used as rDNA template for PCR were obtained and isolated from two cultivars, Francis (FRAN) and Clearfield 151 (CL151).

[d] The top ranked BLAST® hit refers to the first organism associated identified in a search of highly similar sequences (megablast) using the BLAST® database in the blastn suite.

[e] The E-values indicates the probability of distinct alignments expected to occur by chance in the database search. An E-value < 0.05 indicates the score is significant. An E-value of 0 indicates highly significant or distinct alignments with low probability of chance alignments with random accessions in the database.

[f] Max identity is the percentage of base pairs in agreement in comparisons of the query sequences with sequence of the accession identified.

[g] The accession number or identifier of the top ranked of the sequence or isolate in the database.

Table 2. Results of virulence tests conducted in a greenhouse to confirm the pathogenicity of the white isolate I-9E of *Ustilaginoidea* on two rice cultivars. In these tests, spores obtained from 7-day-old potato dextrose broth and wheat bran broth cultures of the isolate were re-suspended in water to a final concentration of 50,000 spores /ml and injected into the unopened boots at different stages of development prior to exertion.

		Total number of boots[c]		Total number	Average no.
Cultivar[a]	Media[b]	Inoculated	Infected	of sori found[d]	Sori/panicle[e]
Roy J	Wheat bran	18	8 (44%)	31	3.9
	Potato dextrose	18	1 (6 %)	1	1.0
Neptune	Wheat bran	12	7 (58%)	21	3.0
	Potato dextrose	12	4 (33%)	7	1.8

[a] Cultivars used in this study were previously shown to be susceptible to green false smut.

[b] The type of broth media used to culture a white isolate of *Ustilaginoidea* (I-9E) for one week prior to inoculation.

[c] The total number of boots inoculated from each cultivar, media type combination, and the number of panicles infected by White Smut out of 18 totals. In parentheses, a percentage of infected panicles out of the total number of inoculated panicles for each cultivar, media type combination.

[d] Total number of sori counted on panicles from each cultivar, media inoculum type combination.

[e] The average number of sori calculated by dividing the number of infected panicles by the total number of sori found for each cultivar, media inoculum type.

Fig. 1. Rice plant infected by black and white forms of *Ustilaginoidea* in the field. Figure 1A shows a white sorus similar to those described for *Ustilaginoidea albicans* (Honkura et al., 1991; Wang and Bai, 1997) and a black or dark green sorus more typical of *Ustilaginoidea virens* as previously found in Arkansas, USA. Figure 1B shows white sori typical of those produced on panicles of Neptune and Roy J in greenhouse tests conducted in 2013.

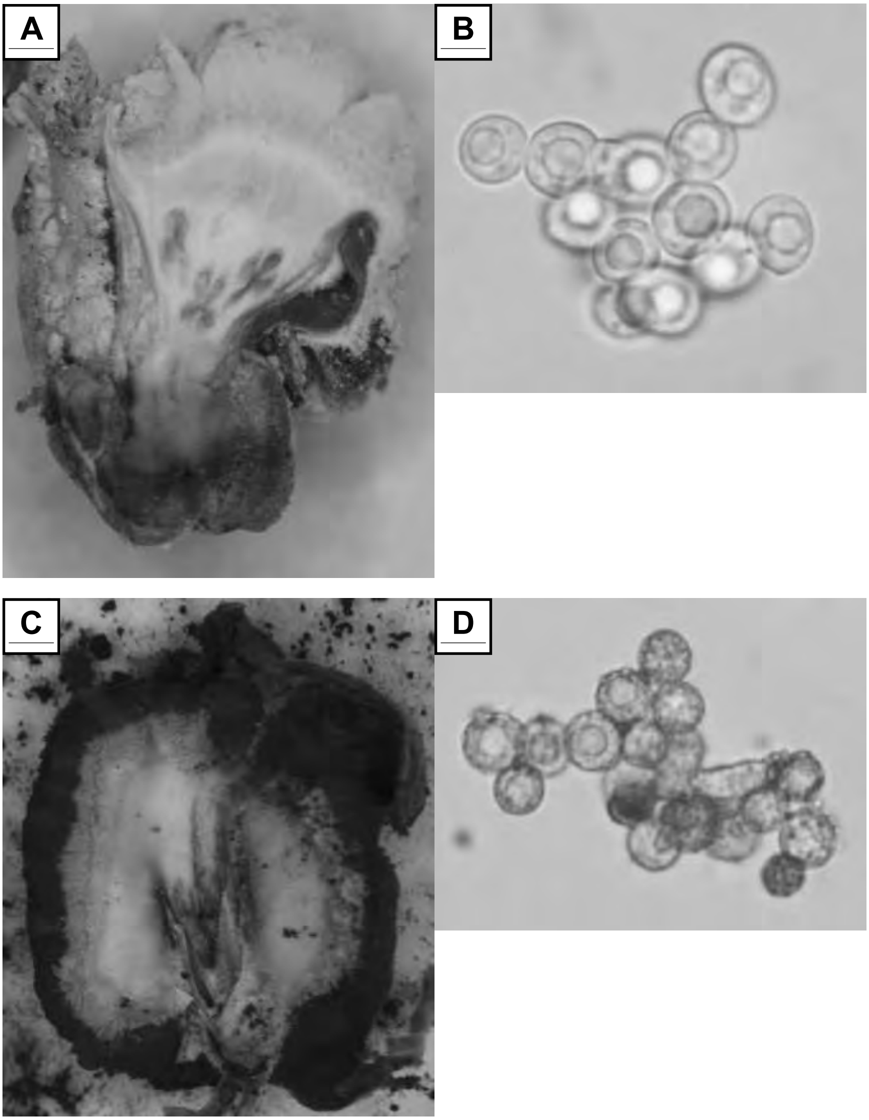

Fig. 2. Rice grains infected by *Ustilaginoidea* in the field. Fig. 2A shows a cross section of a white sorus and conidia. Remnants of floral parts (pistil and anthers) are shown as dark streaks within the sorus mass. Conidia (2B) found in the sorus are hyaline with a smooth surface. Fig. 2C shows a cross section of a black sorus. Remnants of the floral parts (anthers and pistil) are shown as dark streaks within the sorus mass. Conidia found in the sorus (2D) are yellow to dark green and have a spiny or warty surface.

Characterizing Virulence Phenotypes Among U.S. Isolates of *Magnaporthe oryzae* Using International Rice Research Institute Near-Isogenic Lines, U.S. Germplasm, and New Rice for Africa Lines

F. Rotich, C. Feng, Y. Jia, D.E. Groth, and J.C. Correll

ABSTRACT

Rice blast disease, caused by *Magnaporthe oryzae*, is a major constraint to rice production in most rice-production areas, including the southern U.S. In continued efforts to evaluate the effectiveness of resistance (*R*) genes, a total of 33 field and 12 U.S. reference isolates of *M. oryzae* were evaluated for virulence using two sets of differentials developed by the International Rice Research Institute (IRRI). The first set of differentials comprised 31 monogenic lines with 24 *R* genes and, the second set included 20 lines with 14 *R* genes. In addition, four NERICA lines (New Rice for Africa), and five cultivars, three from the USDA World Collection-mini core collection and two rice cultivars from the U.S were evaluated. The two sets of IRRI differential lines discriminated isolates into diverse virulence phenotype groups. The cultivars Li-Jiang-Xin-Tuan-Hei-Gu (LTH) (GSOR 312018) and CO39 (PI 596891), the background cultivars in the development of the IRRI differentials, had *R* genes effective against some of the isolates. NERICA 5 (PI 636846) was resistant to all the isolates evaluated while the other three NERICA lines (NERICA 2, NERICA 12, and NERICA 15) were also highly resistant. Thus, the *R* genes in the NERICA lines could be exploited as potential new sources of resistance to rice blast in the U.S. rice lines. The U.S. cultivars Jumli Dhan (PI 549224) and UZ ROSZ 5 (PI 282207) were the most susceptible lines tested with each cultivar being susceptible to all of the isolates tested. The sets of IRRI differential lines were useful in discriminating virulence phenotypes among U.S. rice blast pathogen isolates. Future efforts continue to focus on phenotyping additional field isolates to fully evaluate the effectiveness of specific *R* genes.

INTRODUCTION

Rice is an important food crop to more than half of the world's population and provides dietary needs to more than 50% of the world's population. Rice blast disease, caused by *M. oryzae*, is a major constraint to rice production in most rice-production areas of the U.S. and worldwide. The most economical way to control rice blast disease is by the use of resistant varieties (Bonman et al., 1992). However, resistance to rice blast disease has been reported to be overcome within a short period of time after resistant lines have been deployed. In order to determine the effectiveness of blast resistance (*R*) genes, there is an urgent need to continually assess the virulence status of isolates.

Previously, assessment of virulence of U.S. rice blast pathogen isolates was performed with the use of a set of 25 to 40 U.S. differential cultivars. These rice differentials have been used to discriminate nine races of *M. oryzae* commonly observed in commercial rice fields over a period of time (Correll et al., 2009). Recently, the International Rice Research Institute (IRRI) developed two sets of differential rice varieties that have been utilized to characterize virulence among internationally collections of the pathogen (Kobayashi et al., 2007). One set of the rice differentials comprises 31 monogenic lines with 24 major R genes within a *Japonica*-type background in the variety LTH. The other set is comprised of 20 near isogenic lines with 14 *R* genes on an *Indica*-type background in the variety CO39.

The New Rice for Africa (NERICA) lines are interspecific rice bred to adapt to the Central and West African rice ecologies where many production constraints, including rice blast disease, exist. The unique traits possessed by NERICA lines have been possibly inherited from their *Oryza glaberrima* parent. The objective of this study was to assess the virulence phenotypes of the U.S. *M. oryzae* isolates of rice using IRRI differentials, U.S. cultivars, and NERICA germplasm.

PROCEDURES

A total of 45 rice isolates of *M. oryzae* from the U.S. were evaluated for their virulence phenotypes. The isolates tested included 12 U.S. reference isolates, archived, and recently collected isolates from fields in the U.S.

The germplasm used in the virulence test included 31 monogenic lines on the LTH background and 20 near-isogenic lines (NILs) on the cultivar CO39 background. Additionally, four NERICA lines and five cultivars, three from the USDA World Collection-mini core collection, and two from the U.S. were also included. The two U.S. cultivars [Francis (PI 632447) and M204 (PI 559472)] included in the test normally act as blast-susceptible check cultivars.

The tests were performed in a greenhouse. Rice seed were sown on sandy soil and Sunshine LC1 potting mixture at a ratio of 2:1 in plastic flats and placed in a greenhouse. Inoculation was done 21 days after sowing by spraying 50 ml of a conidia suspension at a concentration of 2×10^5 conidia/ml of water using a compressed air sprayer. Inoculated plants were then incubated for 24 hours in a dew chamber with 100% relative humidity and a temperature of between 21 °C to 22 °C before being moved to the greenhouse at 19 °C to 26 °C. Disease reactions were rated seven days after inoculation using a disease scale of 0 to 9 (0 to 3 non-virulent and 4 to 9 virulent) (IRRI, 2000). The ratings were then categorized as either resistant (rating 0 to 3) or susceptible (rating of 4 to 9) and were then converted into a binary character matrix that was used to build a similarity matrix based on simple matching coefficients. Cluster analysis was used to generate dendrograms based on the disease ratings with arithmetic averages using the statistical methods (UPGMA) of NYSYS-PC.

RESULTS AND DISCUSSIONS

The sets of IRRI differential lines discriminated the isolates tested into diverse virulence phenotype groups. The differentials on the CO39 background grouped the isolates used into two main groups (A and B) (Fig. 1). Each of the two groups, A and B further had three and two major sub-groups respectively (Fig. 1). Isolates A598 and 49D designated as race IB49 (Correll et al., 2000) were grouped together by these differentials. However the other isolates belonging to race IB49 (ZN17, A119, ZN62, and ZN37) did not group together (Fig. 1). The same was observed on isolates of race IE1; isolate ZN36 and ZN41 grouped together but the other isolates (ZN7and ZN9) of this race were grouped elsewhere. Similarly, the other isolates belonging to the other races were not placed in the corresponding group for instance isolate ZN15 (race IB1) and isolate ZN46 (IC1). Similar observations were made for other isolates with a known race designation. However, race designations of some other isolates used in this test have not been determined. The generally less virulent isolates 6360-1, 6360-3, JUM1, JUM2, JUM3, UZR1, and UZR2 grouped together with the Louisiana isolates LU8-7, LU8-7, LU12-8, LU6-4, and LU1-4.

The differentials on the LTH background also grouped the isolates used into two main virulence phenotype groups (A and B) (Fig. 2). Group A further subdivided the isolates into another two broad groups (1 and 2), but group B had only isolate IB54 as the only isolate in the group. As previously observed for the differentials on CO39 background, isolates A598 and 49D both belonging to race IB49, grouped together. However, the other isolates in race IB49 (ZN62, ZN37, A119, ZN17, and 49D) did not group together (Fig 2). Similar observations were made for other isolates with known race designation.

Overall, there was no correspondence between virulence phenotype grouping based on the previously known race designation and that of CO39 and LTH grouping. Our observations also showed that both cultivars; LTH and CO39 that acted as the background varieties have resistance genes that are effective against some of the blast isolates evaluated.

NERICA lines were resistant to most of the isolates that were evaluated (Fig. 3), hence NERICA lines did not help in virulence discrimination among the isolates evaluated. However, the *R* genes in these lines could be exploited as potential new sources of resistance to rice blast in the U.S.

The cultivars Jumli Dhan and UZ ROSZ 5 were the most susceptible cultivars among the isolates evaluated (Fig. 3). Isolates recovered from these two cultivars were not virulent on all the other rice lines evaluated in this experiment.

SIGNIFICANCE OF FINDINGS

The sets of IRRI differential lines can be useful in the virulence determination and discrimination among U.S. rice blast pathogen isolates. Further, in the virulence phenotype determination of the U.S. blast isolates, NERICA 5, and Jumli Dhan could be included as the resistant and susceptible lines, respectively. Lastly, the resistance genes in the NERICA lines could be exploited as potential new sources of resistance to rice blast disease in the U.S. rice lines.

ACKNOWLEDGMENTS

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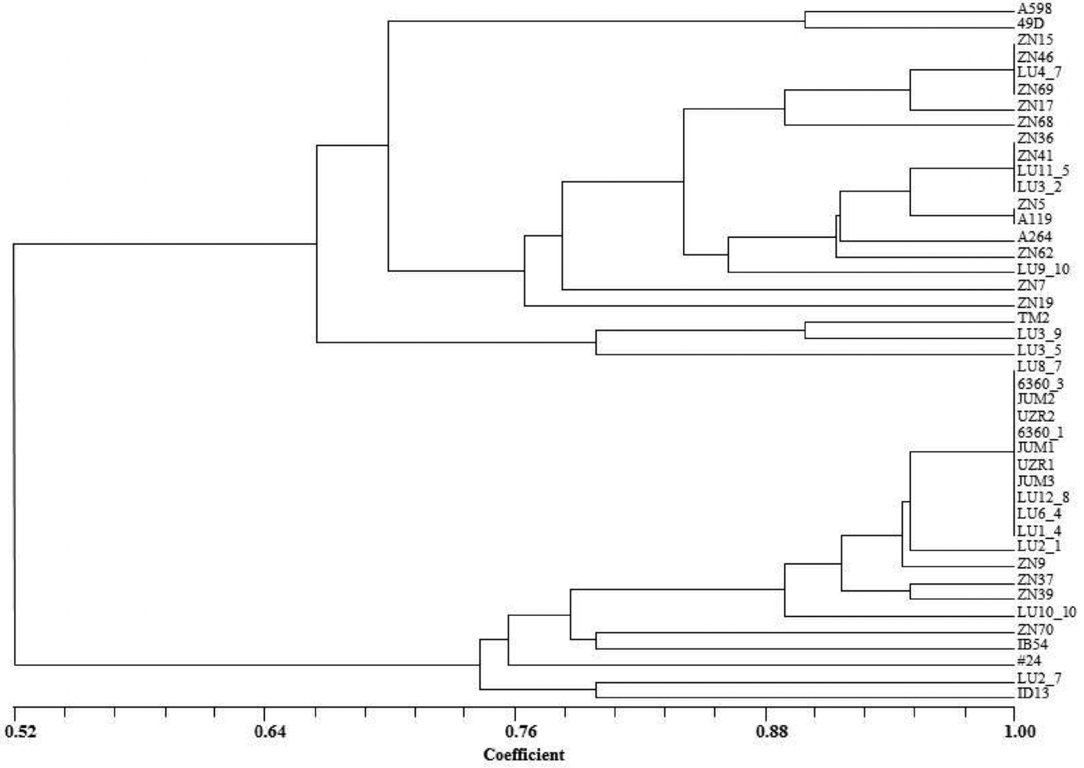

Fig. 1. Virulence diversity of U.S. isolates of *M. oryzae* identified using International Rice Research Institute near-isogenic lines with the cultivar CO39 background. CO39 was included in the blast isolate characterization.

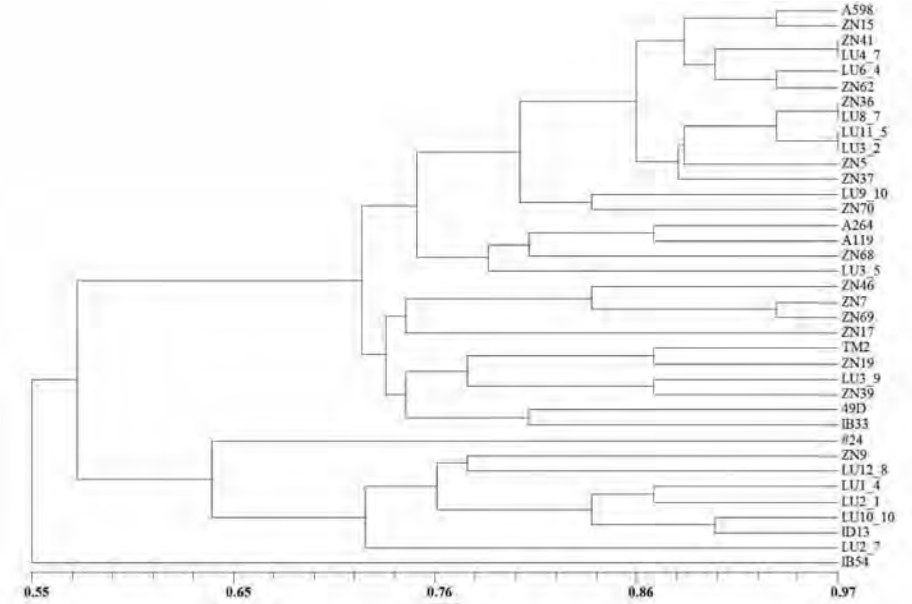

Fig. 2. Virulence diversity of U.S. isolates of *M. oryzae* identified using International Rice Research Institute near-isogenic lines on the cultivar Li-Jiang-Xin-Tuan-Hei-Gu (LTH) background. LTH was included in the isolate characterization.

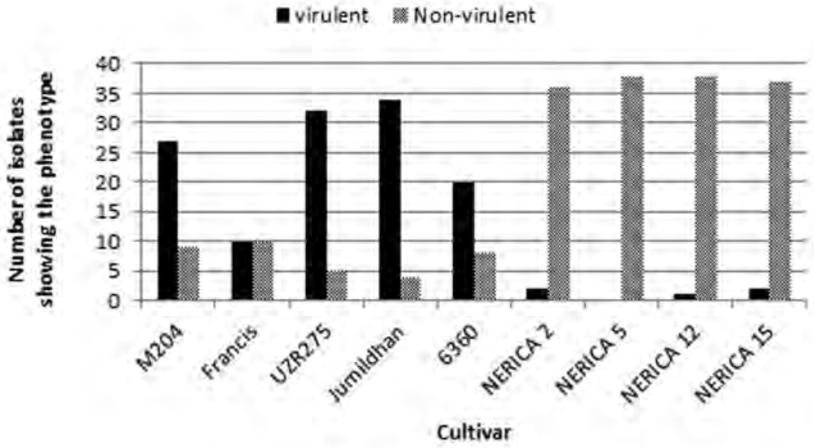

Fig. 3. Virulence phenotypes of U.S. isolates of *M. oryzae* based on U.S. rice lines and New Rice for Africa (NERICA) lines.

PEST MANAGEMENT: DISEASES

Colonization of Rice Florets and the Development of Sori on Rice Cultivars Susceptible to *Ustilaginoidea virens*

D.O. TeBeest and A.C. Jecmen

ABSTRACT

False smut, caused by *Ustilaginoidea virens*, was first found in Arkansas in 1997 and the disease has rapidly spread to most counties in which rice is grown. The disease is normally identified by the presence of orange and black sori (= spore balls, pseudomorphs) that appear on the maturing heads or panicles. The erratic nature of the occurrence of this disease on the cultivars grown in the Arkansas and over time has hampered the development of effective management strategies for this disease. In 2012 and 2013, we conducted several experiments to determine if florets removed from unopened boots were colonized by *U. virens* in greenhouse experiments. The interactions of inoculum (prepared from different culture media) and cultivars on the subsequent development of false smut sori on panicles was investigated in greenhouse experiments. The results show that amplification of total DNA extracted from the florets of three cultivars by polymerase chain reaction (PCR) produced amplicons consistent with *U. virens* and that inoculation with spores from different inoculum sources affected the subsequent development of sori on two susceptible cultivars.

INTRODUCTION

False smut of rice is caused by the fungus *Ustilaginoidea virens* and it has been in the United States for many years. The disease was found for the first time in Arkansas in 1997 in 17 fields in northeast Arkansas with disease incidences ranging from <1% to 6% (Cartwright et al., 1998, Cartwright and Lee, 2001). The disease is characterized by the production of sori on rice panicles at maturity (Fig. 1A, B) on plants that had appeared to be healthy until flowering. It has been previously reported that this disease does not typically affect yield but it can be very serious causing quality issues due the presence of the sori in harvested grain and to the production of ustiloxin, a microtubule inhibitor toxic to animals (Koiso et al., 1992; Miyazaki et al. 2009). More recently, the literature suggests that yields can be significantly reduced (Hedge and Anahosur, 2000; Zhou et al., 2003).

Knowledge concerning the disease cycle and epidemiology of *U. virens* is minimal and incomplete (Lee and Gunnell, 1992). It was believed that primary infection occurs when spore balls release spores into the air which infect developing flowers. Spore balls developing on panicles release spores, to continue the disease cycle, late into the growing season (Cartwright and Lee, 2001). However, reports by Ashizawa et al. (2010), Brooks et al. (2009, 2010), Ditmore and TeBeest (2006) and Ditmore et al. (2007), Ikegami (1960), and Zhou et al. (2003) suggest that rice plants may become colonized from inoculum carried on seed and/or in soil within a few days to weeks after emergence. Schroud and TeBeest (2006) showed that spores of the fungus germinated on roots of rice seedlings within hours after inoculation in laboratory studies. In 2010, TeBeest and co-workers concluded that seedlings appeared to be colonized by the fungus within three weeks after their emergence from soils infested with different concentrations of spores based on polymerase chain reaction (PCR) analysis of seedling tissues (TeBeest et al., 2011). Further, reports show that sori can be produced on flowers of many cultivars within 14 to 30 days after injection of spores into rice boots prior to exertion from the sheaths in greenhouse and field experiments (Ashizawa et al., 2010; Guo et al., 2012; Tang et al., 2012). Ikegami (1960) suggested that the developmental stage of panicles may affect the incidence of infection after boots are inoculated. There have also been reports suggesting that culture media may have significant effects on the subsequent infection of rice by *Ustilaginoidea* (Wang et al., 2008).

In this report, greenhouse experiments were conducted to determine if florets still encased within unopened boots of plants near maturity and grown from seed taken from infected panicles were colonized by *U. virens* prior to their exertion from the boots. Experiments were also conducted to determine 1) if inoculation of boots at different developmental stages with a specific isolate of *Ustilaginoidea* resulted in a significant proportion of the inoculated panicles becoming infected by the fungus in greenhouse experiments, and 2) if inoculum prepared from different culture media had a significant effect on the rate of infection.

PROCEDURES

Seeds of the rice cultivars used in this study to test floret colonization were obtained from field tests conducted at the University of Arkansas System Division of Agriculture Newport Extension Center (NEC), near Newport, Ark., and the University of Arkansas System Division of Agriculture Pine Tree Research Station (PTRS), near Colt, Ark., in 2012 and from the University of Arkansas System Division of Agriculture Rice Research and Extension Center (RREC) near Stuttgart, Ark., as indicated below by experiment. Field experiments were conducted at the PTRS. Greenhouse experiments were conducted in the Rosen Center greenhouses at the University of Arkansas, Fayetteville, Arkansas.

In the field experiments, the seedlots were visibly infested with sori of *U. virens*. Some seeds were also visibly contaminated (blackened) with false smut spores. In the field studies, four, 14.1-oz (400-gram) samples of seeds of each of three cultivars, Clearfield 151, Francis, and Wells were prepared and placed individually in envelopes. Treatments (= cultivars) were planted in a field with a history of false smut in a randomized complete block design with four replications of each treatment. Plots were 5 ft wide × 25 ft long and consisted of 7 rows with a 7-inch spacing between rows. The design of the test (randomization and length of each plot) was intended to minimize differences that might occur within the area with respect to soil fertility (pH, EC, macro- and micro-nutrient levels) which can affect incidence of disease (Brooks et al., 2009, 2010). Plots were planted on 18 May 2012 at Pine Tree and seedlings began to emerge on 25 May 2012. Plots were treated with several herbicides, including 0.5 lb/acre Facet and 2 oz/acre on 18 May 2012 and 4 qt/acre Stam and 0.5 oz/ace of Permit on 30 May. In addition, 0.8 oz/acre Clincher and 0.25lb/acre of Facet were applied on 10 July 2012. Plots were also treated with 150 units of nitrogen (N, 435 lb/acre urea) applied preflood on 21 June 2012. The plots were put into permanent flood on 22 June 2012. Plots were drained on 1 October 2012 and all plots were harvested on 21 October 2012.

Symptom Development, Disease Incidence and Collection of Infected Panicles

In order to determine when signs and/or symptoms of false smut appeared in the tests on the five cultivars, all plots at Pine Tree were examined daily beginning in mid-August, 2012, with the onset of booting of the first cultivar. Disease surveys of all plots began at booting and the average number of infected panicles/10.4 ft^2 was determined for each plot by counting the number of infected panicles/10.4 ft^2 (= m^2) by two experienced investigators. Data on disease incidence (no. of infected panicles/10.4 ft^2) were recorded beginning with the first appearance of false smut sori in any plot and continued, on a weekly basis, until a final determination was made on all cultivars in late September to permit full expression of the disease on all cultivars. Two random counts were made at two locations within each plot in rows exclusive of edge rows. These counts were averaged for each plot. After all cultivars reached maturity and after the data on the incidence of false smut were collected, 15 to 20 infected panicles were collected at random from the center rows within each plot. The panicles were pooled as a collection for each plot (replicate) and placed in paper bags, then placed in boxes before transport to the laboratory. In the laboratory, the total number of sori per panicle was determined by counting the number of typical sori on 10 randomly selected panicles from each individual plot. Thus, we collected 4 replications of 10 infected panicles from each treatment. The data is reported as an average of 4 replications for each cultivar. Seeds of three rice cultivars (Clearfield 151, Francis, and Wells) were obtained directly from the visibly infected panicles collected from our field tests at Pine Tree in 2012.

Colonization of Florets by *U. virens*

Individual and visibly healthy seeds, randomly selected from the panicles above, were sown into square peat pots containing field soil collected from fields with a history of false smut at Newport, Ark. The peat pots were placed in individual pans well watered from above, then set aside in the laboratory for several days until the seedlings had germinated and grown to approximately 4 inches to 5.9 inches (= 10 cm to 15 cm) tall. At that time, seedlings were transplanted into gallon pots containing the same field soil in the fully enclosed greenhouse. The one-gallon pots were placed in plastic containers. When plants began tillering, the pots were flooded in the containers and they were grown to maturity. Plants were fertilized with urea at tillering (5 grams/bucket) and treated with appropriate insecticides to contain mites. When plants had reached the booting stage, we randomly selected 5 booted panicles prior to the boot-split from each of the three cultivars. The booted panicles were aseptically cut from the stems, placed in plastic zip-loc bags and taken immediately to the laboratory. They were placed at 4 °C until used for DNA extraction.

In the laboratory, panicle samples were aseptically opened and 8 florets (Fig. 2) were randomly removed to test for the presence of *U. virens* by PCR methods previously described (Ditmore and TeBeest, 2006; Ditmore et al., 2007; TeBeest et al., 2011; Zhou et al., 2003) with some modifications. Extraction of total DNA from florets was done according to the Epicentre® QuickExtract™ manufacturer's recommended protocols. Single florets from the panicles were placed into 1.5-ml polyethylene tubes on ice containing 100 µl of QuickExtract™ Plant DNA extraction buffer. The samples were briefly vortexed and then incubated in water baths in extraction buffer at 65 °C for six minutes then incubated at 98 °C for two minutes. All DNA samples were stored at 4 °C until used as template in PCR. For PCR, *Ustilaginoidea virens* allele-specific primary-PCR primers 5'-ccggaggatacaaccaaaaaaaactct-3' (US1-5), 5'-gctccaagtgcgaggataactgaat-3' (US3-3), and nested-PCR 5'-caatgcatgtctgagtggattttg-3' (US2-5) 5'-ccaacaccaagcgcaagacaga-3' (US4-3) primer pairs, as designed by Zhou et al. (2003), were obtained from Integrated DNA Technologies (IDT, Coralville, Iowa) and reconstituted to 20 µM. These primer pairs were used to amplify the 380 and 232-bp conserved rDNA sequences specific to *U. virens*, respectively. Nested-PCR amplification was accomplished in a Bio-Rad PTC-200 Gradient i-Cycler (Bio-Rad Laboratories, Hercules, Calif.) or in a Techne 512 thermocycler (Techne 512 thermocycler, Techne Inc. 3 Terri Lane, Suite 10, Burlington, N.J.). Each 50 µl PCR reaction was prepared on ice to contain 21 µl of sterile water, 1 µl of each primer, 1.5 µl of DNA template, 0.5 µl FailSafe™ PCR Enzyme Mix, and 25 µl of the FailSafe™ Master Mix (alternatively, 25 µl of the FailSafe™ PCR Premix C + 1% polyvinylpyrrolidone) instead of sterile water. The 50-µl reactions, prepared for sequencing or routine nested-PCR diagnosis that utilized 2X Taq Master Mix, contained 21.5 µl of sterile water, 1 µl of each primer, 1.5 µl of DNA Template, 25 µl 2X Taq Master Mix. Prior to each PCR reaction, a PCR reagent master mix was prepared and the reagents were aliquoted to 8 tube PCR strip tubes with attached strip caps on ice prior to loading the template DNA. Templates in the primary reactions consisted of 1.5 µl from DNA quick extractions, while the nested reaction utilized 1.5 µl of amplicons reaction product from the first reaction as a template. In each set of reactions, negative reagent and positive (DNA from I-6E) controls were included. Thermocycling conditions for primary and nested-PCR were as follows: initial denaturation was done at 96 °C for two minutes to separate DNA into single strands, followed by 30 replication cycles at 95 °C for 20 seconds, annealing at 54 ° C for 30 seconds, and finally, extension at 72 °C for 30 seconds. After the 30 cycles, final extension was held at 72 ° C for seven minutes and then held at 4 °C until the products were resolved by electrophoresis in 2% agarose containing ethidium bromide. A floret was considered to be infected if a band consistent with bands produced by amplification of DNA of *U. virens* (= controls) was found.

Development of Sori in Greenhouse Experiments

Seeds of two rice cultivars (Neptune and Roy J) for these tests were obtained from the RREC. Five to eight seeds were planted in 2-inch peat pots containing soil taken from fields with a history of false smut obtained from the NEC. Seedlings were grown in the peat pots until they reached the 4-lf stage and then three peat pots were transplanted into 1-gal pots containing field soil from the NEC. Plants were grown until tillering before the pots were brought to full flooding after placing the gallon pots in buckets as described above. The plants were then grown until they reached the booting stages. Individual boots at different stages of development on the plants were randomly selected and inoculated with isolate I-9E of *Ustilaginoidea virens*, an isolate obtained from a white sorus using techniques previously described by Wang et al. (2008). Isolate I-9E was initially grown on potato dextrose agar at 26 °C for 7 to 14 days before 1-cm blocks from colonies were placed into 25-ml of potato dextrose broth (PDB) or wheat bran broth (WBB). Broth cultures were grown on a rotary shaker at 125 rpm for 5 to 10 days at 25 °C. Conidia were harvested from the cultures by pouring off the culture fluid into a centrifuge tube through several layers of cheese cloth followed by centrifugation at 7500 rpm. The supernatants were then decanted from the centrifuge tubes and the pelleted conidia were resuspended in sterile distilled water and diluted to a final concentration of approximately 50,000 conidia/ml. Between 0.5 and 1 ml of the suspensions was injected into the unopened boots of Roy J and Neptune plants that had been grown in an enclosed greenhouse. After inoculation, plants were placed in a dew chamber at 18 °C to 20 °C for 48 hours followed by incubation at 24 °C for 120 hours in air conditioned rooms while still enclosed in plastic bags. After 120 hours, the bags were removed and plants were moved to the fully enclosed greenhouse. Controls were inoculated with water and treated similarly. All plants were observed daily for 35 days after inoculation. To replicate the dew often deposited on panicles under field conditions (Fig. 1A), panicles were sprayed with water each night until droplets formed on developing seeds to encourage the enlargement of sori. The post dew-period treatment was discontinued 30 days after inoculation.

Statistical Analyses

The design for the field experiment was a randomized complete block design with four replications of each treatment. An analysis of variance of the means of each treatment was conducted using PROC GLM of SAS v. 9.2 and Fisher's Protected Least Significant Difference test (LSD) at $P = 0.05$ was used to separate differences between the means. For the greenhouse floret tests, each of the five pots was considered a repetition of a treatment (= cultivar) with each of the five panicles and 8 florets sampled from each pot considered as a replication of a treatment.

RESULTS AND DISCUSSION

Symptom Development and Disease Incidence

As expected, visible symptoms of infection did not appear on any of the cultivars in the field study until late August, 2012, when young sori, still encased within a membrane (Fig. 1A) and a few orange sori were found on a few panicles already at the flowering stage (Fig. 1A). The infected plants were randomly distributed throughout the test although there were differences in the incidences of false smut between treatments. There were no obvious indications of disease aggregations within or between plots at any time. The appearance of sori changed from the initial membrane covered structure as shown in Fig. 1A to the mature structures shown in Fig 1B within two to three weeks. We observed that the diameter of the sori appeared to increase after light rains or with the deposition of heavy dews on the panicles.

Disease levels were assessed over several weeks as described above by counting the number of visibly infected heads at multiple locations within each plot and these data were then averaged for each plot. A panicle was considered infected if it had a single clearly identifiable sorus as shown in Fig. 1A or B. The average number of panicles visibly infected by false smut/10.4 ft^2 was collected twice before harvest. As we reported in 2012, there were no obvious or statistical indications of secondary infections (by spores from sorus leading to formation of another generation of sori) and the average number of infected panicles/10.4 ft^2 reached maximal levels approximately 10 to 14 days after the first appearance of sori in the plots. Although, there were statistical differences in the number of infected panicles per square meter among the three cultivars, there were no significant differences in the number of sori found on the infected panicles and all cultivars were assigned to the same rating class as reported by Lu et al. (2009).

Colonization of Florets by *U. virens*

In 2013, we conducted greenhouse experiments in which we removed florets from unopened panicles on plants grown from seeds that we had collected in 2012 in order to determine if we could detect bands consistent with *U. virens* after PCR of total DNA extracted from the florets (Fig. 2). In these tests, we harvested 5 panicles at random from plants grown from the seed of each cultivar and then harvested eight immature florets from unopened boots from each panicle for a total sample of 40 florets. We considered a floret to be infected if a band was detected after PCR analysis and to be healthy if a band was not detected. The results show that a significant number of florets produced bands after PCR analysis and electrophoresis of reaction samples. An

ANOVA of the data showed no significant differences in the number of infected florets in the boot or in the percentage of florets in the boot between the cultivars in the test (Table 2). However, the results in Table 3 show that an average of 75% of the florets collected from Clearfield 151, an average of 40% of the florets collected from Francis, and an average of 27.5% of the florets collected from Wells indicated the presence of *U. virens* within a floret. The data also show that the number of florets presenting bands ranged widely among the cultivars; from 3 to 8 (out of 8 tested) for Clearfield 151; from 1 to 4 for Francis; and from 0 to 7 for Wells in these tests. The lack of significant statistical differences between the cultivars may have resulted from the small sample size or from the fact that all three cultivars were susceptible to *U. virens* in our field tests as reported here and earlier (TeBeest and Jecmen, 2012, 2013). It may also have been affected by the sampling procedure because we sampled panicles from different developmental stages; from immature to near maturity and panicle exertion.

Greenhouse Inoculations and Sorus Development

The incubation period, or the time between inoculation and the first appearance of symptoms of a disease under conducive conditions, is one of several important components of a disease cycle and disease component or fitness analysis. In 2013, we conducted greenhouse experiments in which two susceptible cultivars were inoculated (TeBeest and Jecmen, 2012, 2013) with spores of a white strain of the false smut fungus harvested from two different media. The appearance of sori on the panicles growing from the inoculated boots was then measured over time. In the greenhouse, the first sori appeared approximately 16 days after inoculation (Fig. 3). However, we also observed grayish-white mycelial-like growths between the glumes on some panicles in the greenhouse before day 16 but did not consider these as sori in this report. In the greenhouse, many of the sori remained encased within the membrane typical of false smut (Fig. 1A) although others developed sufficiently so that the membranes opened; slightly exposing the spores that had developed within the membranes. The spores produced in the sori were identical in morphology and color to the spores in the original inoculum. A total of 60 sori developed on all of the inoculated panicles between 16 and 31 days after inoculation (Fig. 4); 32 on 18 panicles of Roy J, and 28 on 12 panicles of Neptune (data not shown). Most of the sori observed on Roy J resulted from inoculation of panicles at growth stage seven, when the distance between the flag leaf and penultimate leaf was 4.7 inches to 5.9 inches (= 12 cm to 15 cm); whereas, most of the sori produced on Neptune were found on panicles inoculated at growth stage 4 when the distance between the flag and penultimate leaves was 2.4 inches to 3.1 inches (= 6 cm to 7.9 cm; data not shown). This is similar to the reports of Ikegami (1960) who also found that the development of sori on panicles was dependent on the developmental stage of the booted panicle at the time of inoculation.

The ANOVA evaluations of the number of sori produced on cultivars indicated that there were no significant differences in the total number of sori produced on panicles between cultivars (Table 4). However, ANOVA showed that there were very significant effects of media, cultivar*media interactions, days after inoculation, and media*days after inoculation interactions on the number of sori produced on panicles of the two cultivars (Table 4, Fig. 4). Approximately 50% of the panicles inoculated with spores taken from WBB produced sori, whereas only 16.7% of the panicles inoculated with spores from PDB produced sori (data not shown). The effects of media on expression of disease have been previously reported by (Wang, et al., 2008).

We have previously reported that the time required for false smut sori to first appear and to reach maximum incidence levels on cultivars grown in the field in Arkansas was approximately two weeks (TeBeest and Jecmen, 2012, 2013). The time between the first visible appearance of these sori and maximal expression of disease was approximately two weeks in the greenhouse experiment. The disease progress curves for sporulation of false smut appear to be very steep and different from the disease progress curves for rice blast or anthracnose diseases of grain sorghum and northern jointvetch and *Alternaria macrospora* on *Anoda cristata*, diseases that have significant secondary dispersal and infection cycles (Li and TeBeest, 2009; Long et al., 2001; Moore et al., 2010; Yang and TeBeest, 1993).

Hedge and Anahosur (2000) and Lu et al. (2009) attempted to describe susceptibility of different cultivars on the basis of the number of spore balls/panicle. In 2012 and 2013, TeBeest and Jecmen used a similar assessment tool to evaluate a larger number of cultivars and found statistically significant differences in the number of false smut sori on panicles for the cultivars used in that study. The data in Fig. 3, show the number of sori developing on the two cultivars in the greenhouse studies. The data are not significantly different statistically, as expected, since these two cultivars were considered to be susceptible in previous tests (2011 and 2012). However, it is interesting that even though there was a greater number of sori developing on panicles of the cultivars after inoculation with spores obtained from WBB cultures than when inoculated with inoculum obtained from PDB cultures (Table 3), the greenhouse inoculations closely approximated the number of sori found on these two cultivars in the field where large differences were also found between locations with different soil types.

SIGNIFICANCE OF FINDINGS

False smut is an emerging and increasingly significant pathogen of rice in Arkansas. Although first reported in only 17 fields in Arkansas in 1997, it has since rapidly spread to other fields and it is now considered to be widespread within the state. Disease resistance is a mainstay of managing many plant diseases so identification of germplasm that demonstrate resistance or tolerance to false smut across the different soil and environmental conditions in Arkansas may be crucial to successful and integrated management programs for this disease. Based on the preliminary data in this test and on the evidence already in the literature, we are continuing a project to develop the precise methodologies necessary to identify and evaluate germplasms across locations and fields with reasonable assurances of success.

Our understanding of the disease cycle and epidemiology of this disease is still rudimentary. Given that contaminations of seed and soil with viable spores may lead to the infection of rice in the field, new questions arise relative to the roles that inoculum, cultivar genetics, and growth stages, and the possible existence of pathotypes may have on the general incidence and severity of false smut in Arkansas. Based on the published evidence, it also appears that several factors, including soil type, soil moisture, cultivars, and isolate specificities, cultivar developmental stages, inoculum preparation (greenhouse evaluations), and environmental conditions at the time of inoculation and during subsequent development of sori may be of importance at the various stages during one disease cycle, beginning with the infection of seedlings and up to and including the actual development of sori on mature plants. Further work on the epidemiology of the disease across cultivars and locations in relation to flowering could provide useful information regarding management of this disease with fungicides or disease resistance.

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Table 1. The mean number of infected panicles counted/m^2 and the number of sori found on panicles of selected cultivars planted in field plots grown at the Pine Tree Research Station, near Colt, Ark. in 2012.

Cultivar	Infected panicles†	No. of sori†	Rating class‡
	(no./10 ft^2)		(no./panicle)
Wells	1.25 A	2.08	2
Francis	3.10 A	2.86	2
Clearfield 151	12.50 B	2.66	2

† Means followed by the same letter within a column are not significantly different according to LSD at $P = 0.05$. Data on infected panicles/m^2 are the averages of two samples per plot with four replications per treatment. The number of sori per panicle is based on 6 samples of 10 randomly selected infected panicles per cultivar.

‡ Disease rating classes are as reported by Lu et al. (2009). Disease rating classes were assigned based on the average of the number of spore balls/six samples of ten panicles per cultivar. Rating class 0 = 0 sori/panicle, class 1, one sorus per panicle; class 2, two sori per panicle; class 3, three sori / panicle; class 4 six to nine sori per panicle and class 5, greater than ten sori/panicle.

Table 2. Analysis of variance of the number of florets infected in the boot stage in greenhouse experiments, the percentage of florets infected in the boot stage, the number of infected panicles/m² and the number of sori on panicles collected from field plots.

Variable/ (Date)†	Source	DF	Sums of squares	Mean square	F value	Pr > F
Number florets infected in the boot						
	Cultivar	2	38.800	19.400	3.44	0.0658
	Error (MS)	12	67.600	5.63	4.075	
Percentage florets infected in the boot						
	Cultivar	2	6062.500	3031.250	3.44	0.0658
	Error (MS)	15	184.038	12.484		
Number of infected panicles/m²						
	Replication	3	2.500	0.833	0.52	0.6842
	Cultivar	2	270.375	135.187	84.27	
<0.0001						
	Error (MS)	6	9.625	1.604		
The number of sori found on 70 panicles						
	Cultivar	2	2.014	1.007	2.38	0.1268
	Error (MS)	15	6.355	0.424		

† Variables = values for the dependent variable, no of panicles/m², are given as the average number of infected panicles per square meter found in replicated plots of five cultivars collected at two different times after first appearance. The dependent variable, sori/panicle, was based on the number of sori counted per panicles collected from 10 infected panicles from each replication of each cultivar (= treatment). Analysis of variance evaluations were performed using a general linear models (GLM) procedure in SAS.

Table 3. The number of florets of three selected rice cultivars grown in a greenhouse from infested seeds testing positive for the presence of *U. virens* following nested polymerase chain reaction using primers specific for the fungus. DNA was extracted from the individual florets before emergence of the panicle from the boot.

Cultivar[†]	Panicle no.	No. florets tested	Number PCR positive	Average florets infected	
				(no.)	(%)
Clearfield 151	A	8	3		
	B	8	7		
	C	8	8		
	D	8	8		
	E	8	4	6.0 a	75.0 a
Francis	A	8	2		
	B	8	1		
	C	8	4		
	D	8	5		
	E	8	4	3.2 a	40.0 a
Wells	A	8	0		
	B	8	0		
	C	8	7		
	D	8	3		
	E	8	1	2.2 a	27.5 a

[†] Plants were grown from seed harvested from panicles visibly infected by *U. virens* in tests conducted at the Pine Tree Research Station in 2012. Seeds were planted in the greenhouse and grown to the booting stage at which time five panicles still in the booting stage were removed from the plants and taken to the laboratory. In the laboratory, 8 florets were removed aseptically at random from each of the panicles for a total of 40 florets from each cultivar. DNA was extracted from the individual florets and tested by nested PCR for the presence of DNA consistent with *U. virens* as reported by Zhou et al., 2003.

Table 4. The results of the analysis of variance of the interactions of 2 cultivar, 2 media and time (5 sampling points after inoculation) after inoculation on the number of sori produced on matured plants after injection of rice plants at the boot stage in greenhouse experiments. The plants were grown from seed in soils taken from a field with a history of false smut and grown in a greenhouse until inoculated with strain I-9E of *Ustilaginoidea* when the boots were in one of eight different stages of maturity and given a dew period followed by post dew period treatments.

Source	DF	Sum of squares	Mean square	F value	Pr > F
Model	19	717.26667	37.751	7.28	<0.0001
Error	40	207.333	5.183		
Type I and III error					
Cultivar	1	8.0667	8.0667	1.56	0.219
Media	1	405.6	405.6	78.25	<0.0001
Cultivar*media	1	338.4	38.4	7.41	0.009
Days	4	168.766	42.192	8.14	<0.0001
Cultivar*days	4	86.233	0.192	0.04	0.997
Media*days	4	86.233	21.558	4.16	0.006
Cultivar*media*days	4	9.4333	2.333	0.45	0.768

Fig. 1. Signs of infection of rice by *Ustilaginoidea virens* found on panicles of one of the more susceptible cultivars in field plots at the Pine Tree Research Station, near Colt, Ark. in 2012. In Fig. 1A, we show sori that are beginning to turn from their initial orange color to the mature dark green found at maturity. Droplets of dew are clearly visible on three of the sori. In Fig. 1B, we show sori that have matured to the typical dark green coloration and from which the chlymadospores are easily released by wind or water.

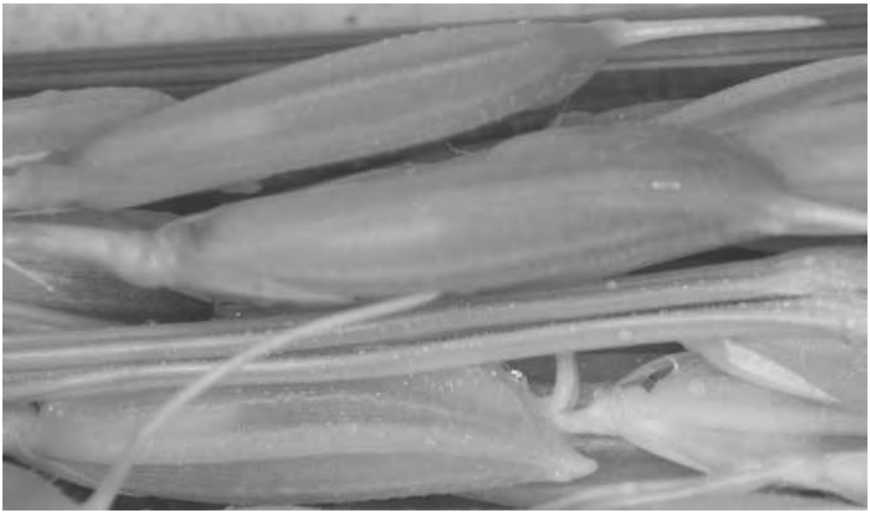

Fig. 2. An example of the florets tested for the presence of *U. virens* by polymerase chain reaction analysis. Florets were aseptically collected from unopened boots of plants grown in greenhouse from seeds collected from visibily infected panicles in 2012.

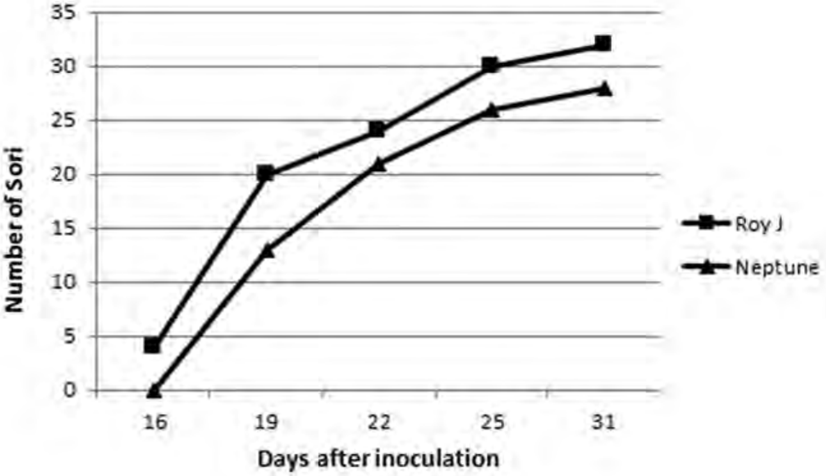

Fig. 3. Development of sori on panicles of Roy J and Neptune after inoculation with spores of a white isolate of *Ustilaginoidea* I-9E.

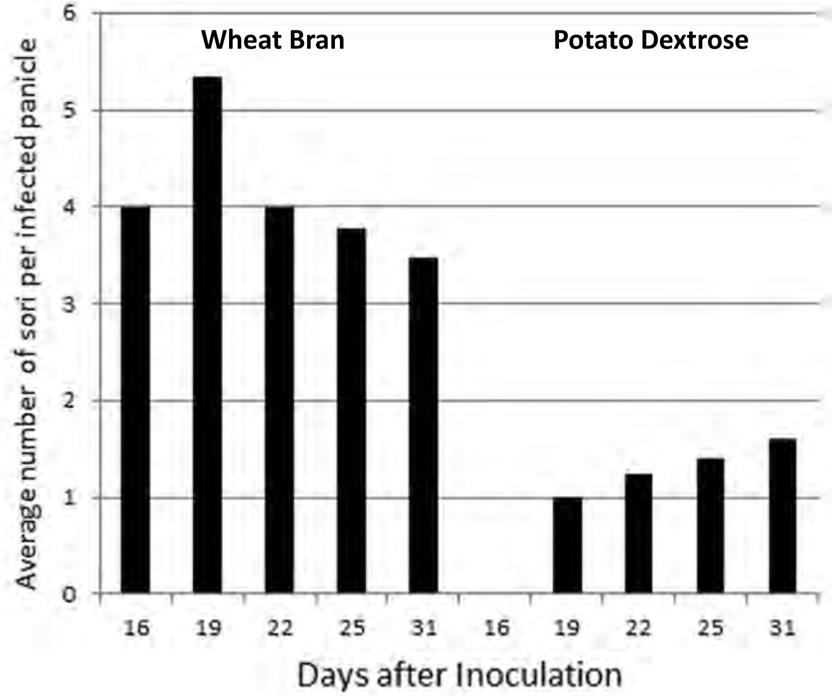

Fig. 4. The average number of sori observed on infected panicles of two rice cultivars after 16 to 31 days inoculation of unopened boots of plants with spores of isolate I-9E of *Ustilaginoidea* harvested from 7-day-old wheat bran broth and potato dextrose broth cultures. The experiment was conducted in a greenhouse in 2013 in the Rosen Center with plants of Roy J and Neptune grown from seed obtained from the Rice Research and Extension Center, Stuttgart, Ark.

PEST MANAGEMENT: DISEASES

Development of Short-Term Management Options for Rice Bacterial Panicle Blight Disease

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ABSTRACT

Field trials were conducted in 2013 at the Rice Research and Extension Center near Stuttgart, Ark., for the second year to evaluate the effects of planting date, water stress, seeding rate, and nitrogen (N) fertilizer on bacterial panicle blight (BPB) disease of rice caused by *Burkholderia* species. Seeds were artificially inoculated to establish a uniform infection. Late-planted plots had significantly higher BPB disease incidence on both Bengal (susceptible variety) and Jupiter (moderately resistant variety) resulting in considerable yield and milling quality losses. Water shortage (stress) showed more of a negative effect on yield than BPB disease on both inoculated and non-inoculated plots. Regardless of the higher BPB disease level, plots with permanent flood had better yields. Total mean water provided in 2013 during the season for the intermittent treatment was 45% less than the flooded. Seeding rate showed no significant treatment effects on disease incidence in Bengal. However, BPB increased in the higher seeded plots of Jupiter (a known moderately resistant variety). Fertility showed significant difference in BPB disease. Mean disease incidence at the rate of 220 lb N/acre was 1.6 times higher than at the 150 lb N/acre rate. Mean disease incidence in Bengal (a known susceptible variety) was 2.75 times higher than in Jupiter. The two fertility levels showed no significant differences in yield or milling quality. Ultraviolet light, microwave, household antimicrobial agents, hot water, freezing, an industrial sanitation chemical, plant extracts, competitor bacteria, silver, and copper compounds were screened for their antibacterial activity on inoculated seeds. However, seed germination was adversely affected with the methods that killed the bacteria. The effect of a plant extract or diluted vinegar coupled with dry heat is under investigation.

INTRODUCTION

Bacterial panicle blight (BPB) has been observed in rice production fields of Arkansas and other southern states with increasing frequency since 1995 (Cartwright, pers. comm.). Extended hot summer nights are favorable to this disease which is thought to be primarily seedborne. The BPB was severe in 2010 and 2011 and can cause up to 60% yield loss under environmental conditions favorable for the disease (Cartwright, pers. comm.). Panicle symptoms typically develop late in the season, which makes predicting disease occurrence difficult. Infected panicles mostly have blighted florets which first appear white to light gray with a dark-brown margin on the basal third of the tissue. Later, these florets turn straw-colored and may further darken toward the end of the season with growth of other opportunistic microorganisms. Heavily infected panicles remain upright due to lack of grain fill. There are no chemical options registered in the U.S. to protect or salvage the crop from the disease. This disease, being dependent on weather and environmental conditions, is sporadic in nature and the causal agents survive in the soil, crop residues, and seeds. Unlike the historic years of 2010 and 2011, BPB pressure was relatively low in 2012 and 2013. The rice season in 2012 was hot and dry and 2013, wet and cool. Both conditions seemed unfavorable for natural prevalence of the disease. The purpose of this research is to examine cultural, chemical, and non-chemical management options that may be used solely or in combination to reduce BPB of rice until plant resistance is identified and incorporated into high yielding and adapted cultivars.

PROCEDURES

Land Preparation and Planting

Test fields cropped the previous year with soybeans were tilled and prepared in the early spring. A preplant fertilizer of Triple Super Phosphate (65 lb/acre), potassium chloride (100 lb/acre), and CoZinco (30 lb/acre) was applied. A burn down application of Gramoxone Inteon was applied to kill weeds or off-type rice. The area was then roto-tilled to loosen the soil and ensure a good seed bed. Planting was done with a Hege 1000 seed drill set to plant 8 rows on 8 inch row spacing with approximately one inch depth. The plots were approximately 5 ft ×14 ft. After planting, the plots were rolled to ensure good soil to seed contact and to seal in moisture.

Evaluation of the Effects of Planting Date on Rice Bacterial Panicle Blight Disease

This is the second year to test if planting dates affect BPB disease severity under Arkansas conditions. Although more than one species of *Burkholderia* species are involved in causing rice BPB disease, tests were carried out using only *B. glumae* because it was more frequently isolated from infected kernels in Arkansas. To obtain uniformly infected seeds and to ensure the survival of the bacteria until cotyledon emergence, an artificial seed inoculation method was utilized. A two- to four-day old culture of *B. glumae* was grown on non-selective King's B medium at 104 °F. The culture was then washed from a petri dish with sterile water to obtain a 1-ml suspension with approximately 106 to 109 cfu/ml (colony forming units per milliliter). The bacterial suspension was mixed with 4 ml salt-sugar buffer (1 g yeast extract, 2.36 g NaCl, 3.4 g sucrose/l distilled water) (Streeter, 2007). The mixture was infiltrated into 40 g of rice seed by applying a vacuum (25 inches Hg vacuum) for 5 min in a loosely sealed mason jar followed by restoring atmospheric pressure with the removal of the lid. The vacuuming process was repeated a second time. Seeds were then covered with 8 g of talc (powder) to absorb excess liquid and to ease planting. The talc shield also served as a buffer between soil and seeds until germination. After emergence, samples of cotyledons were tested for the presence of *B. glumae* on partially selective medium designated, CCNT (Kawaradani et al., 2000). The CCNT agar is a partial selective medium containing 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 adjusted to pH 4.8. In 2013, artificially inoculated seeds of Bengal (susceptible variety) and Jupiter (moderately resistant variety) were planted at the recommended seeding rate of 88 lb/acre. The first and second plantings were done on 19 March and 29 May, four days after last year's third planting date. All treatments were maintained similar to 2012. Panicles with greater than 50% infection per plot were counted. Yield and quality data were also collected.

Evaluation of Water Stress on Bacterial Panicle Blight Disease

Year 2013 was the second test season to determine if water stress affectsed BPB disease severity. Rice varieties of Bengal and Jupiter were planted at the rate of 88 lbs/acre on 16 May. Half of the plots were planted with bacteria inoculated and the other half with non-inoculated seeds. All treatments were replicated four times each in 5-ft × 14-ft plots. In 2013, the intermittent flooding treatment was changed to an intermittent flushing treatment and a moderately resistant variety, Jupiter, was also added in the test. Intermittent flushing treatment plots were allowed to dry down to soil moisture content of approximately 60% for a total of six times before being re-flooded. Soil moisture was monitored and recorded by soil moisture sensors (Irrometer Co., Riverside, Calif.) placed at depths of 2 inches and 4 inches. Water usage was recorded with flow meters (McCrometer, Hemet, Calif.) installed in each of the four bays of the test. The permanent flood bays remained flooded throughout the growing season until drained for harvest. The experiment will be repeated in 2014 as in 2013 to confirm the effect of water treatments on BPB levels using these two rice varieties.

Effects of Excessive Nitrogen Fertilizer on Rice Bacterial Panicle Blight

In 2012, seeding rate and nitrogen fertilizer effects on BPB disease incidence and severity were tested using a split plot design. *Burkholderia glumae*-inoculated seeds of

Bengal and Jupiter were planted at a recommended seeding rate (88 lb/acre) and a high seeding rate (176 lb/acre) on 16 April. Two pre-flood nitrogen rates were investigated: the NST*R recommended rate (150 lb N/ acre) and a rate of 180 lb N/acre. When the 2012 data were analyzed, seeding rate and fertility showed no treatment effects on disease incidence. This lack of detectable differences may be due to the low levels of BPB in early planted plots (April) compared to higher disease pressure found on late planted plots (late May) as shown in other experiments. Therefore, the experiment was repeated in 2013 with modifications: separation of fertility and seeding rate treatments, increase differences between fertility levels with 150 lb N/acre and 220 lb N/acre and planting late (29 May) using completely randomized experimental design.

Evaluation of Effect of Seeding Rate on Bacterial Panicle Blight Disease

In 2013, the experiment was modified such that the seeding rate and N study could be handled separately. Planting was done later on 29 May instead of April. Bacteria-inoculated seeds of Bengal were planted at a recommended seeding rate (88 lb/acre) and a higher seeding rate (176 lb/acre). Land preparation and input application were maintained as in 2012.

Evaluation and Testing of Chemical and Non-Chemical Seed Treatments

Ultraviolet light, microwave, household antimicrobial agents, hot water, freezing, an industrial sanitation chemical, plant extracts, competitor bacteria, silver, and copper compounds were screened on artificially inoculated seeds with *B. glumae*. Seed germination tests were carried out for those that showed some level of positive results in their antibacterial activity. Three seed treatments were applied and preliminary field tests were carried out in the field plots that had rice the previous year. The treatments included: a copper compound, a plant ferment coupled with dry heat, and vinegar coupled with dry heat. The dry heat treatment was at 131 °F for 72 h.

RESULTS AND DISCUSSION

In 2013, plots established with artificially inoculated seeds showed BPB severity much less than in 2012. The wet and cool season discouraged disease development. However, disease severity was noticeable and much higher when earlier planted plots were compared to the third planting (Fig. 1). The trend for BPB disease severity also agrees with the previous year. The mean disease severity on the third planting date was nearly 14 and 6 times higher than the first and second planting dates, respectively (Fig.1). Plots of the third planting had the lowest total yield and head rice yield (data not shown). Head rice yields in May-planted plots were reduced compared to April-planted resulting in 15% and 7% in Bengal and Jupiter, respectively. There was no significant difference on total percent milling between the first and third planting dates. Although, the extent of the bird damage was not measured, grain yield in March-planted plots was influenced by bird feeding both before emergence and after heading (Fig. 2). Therefore, parameter comparisons were made between April-planted and May-planted plots. In the May planting, Bengal showed a 62% yield loss when compared to the yield from the April planting. Likewise, Jupiter showed a 44% yield loss. In both varieties the yield losses were quite significant although the loss may not be totally due to the disease severity. Mean disease incidence in Bengal was 2.75 times higher than in Jupiter. Shorter duration for growth and grain filling associated with late planting could adversely affect yield.

Historically, early planting is generally encouraged to allow adequate time for plant development and grain fill and also to escape some rice diseases such as blast. This study indicated March to April planting dates minimized BPB disease incidence resulting in lower effects on yield and grain quality. Observations in previous years showed BPB disease of rice severe with high temperatures, particularly extended night-time air temperatures above 78 °F. (D. Groth; R. D. Cartwright, pers. comm.). It is not well understood at which crop stage the temperature plays the greatest role and what other factors are involved. Artificial foliage inoculation in another study was effective between boot split and flowering. High humidity, together with prolonged high night temperatures could be key factors. It is likely that favorable temperature and humidity at earlier crop stages up until boot or boot split allow for survival of the bacteria as an epiphyte if the inoculum source is assumed to be seed or soil. These bacteria then move up the crop canopy and eventually become established in the florets. Under lab conditions, *B. glumae* grows well on CCNT or King's B media at temperatures between 98 °F to 104 °F. These bacteria also grow at room temperature but at a slower rate. In 2012, Bengal and Jupiter took nearly three months to reach boot stage. Stuttgart weather data indicated the average air maximums from 78.2 °F to 88.4 °F and the average minimums from 55.4 °F to 68.6 °F for the months of April to June, respectively. The average maximum for July and August was 93.6 °F and 87.1 °F while the minimum 74.5 °F and 70.9 °F, respectively. Average minimum soil temperatures for July and August were 81 °F and 77.7 °F. Soil temperature may play a role in raising the humidity under the canopy for a favorable microenvironment for the bacteria. However, there is no report on the role of soil temperature on the survival or multiplication of the bacteria. With tropical storm Isaac helping spread the disease within plots in the third planting, overall BPB severity in 2012 was much higher than 2013. In the latter year, the crop season was wet and cold. Rice planted on 19 March (first planting date), emerged in 29 days and the second planting (planted on 23 April) emerged in 17 days. Although the third planting date (planted on 29 May) emerged in seven days, most of the inoculum appeared washed away. Seeds in all three planting dates were inoculated similarly and the low disease incidence in 2013 cannot be attributed to the absence of inoculum at the start. The seed inoculation method was proven effective with the third planting date in 2012. Despite the low disease incidence in 2013, the disease data was enough to show a similar trend to that of 2012 in disease severity of both Bengal and Jupiter. The later the planting date the more the disease. The planting date experiment will be repeated again in 2014 to confirm results.

Data from water stress tests showed that in 2013 BPB disease levels were twice as high in flooded compared to water stressed plots (Fig. 3). This trend was similar to what was observed for 2012. In 2013, there was also a significant difference in disease incidence between the two varieties used. In 2012 only Bengal was used. Yield was lower in the water stressed plots compared to flooded plots primarily due to the water shortage itself (Fig. 4). Milling quality of Jupiter was more significantly reduced with the water stressed condition than Bengal (data not shown). Since the disease was sporadic and weather dependent, BPB pressure was low in 2012 and 2013 compared to historical BPB epidemic years of 2010 and 2011. Total mean water provided in 2013 during the season for the intermittent treatment was 45% less than the flooded. The intermittent plots received 2.56 acre-inch and the flooded, 4.66 acre-inch of water during the season. This test will be repeated again in 2014 with intermittent flushing using the same two varieties, and a similar water-deficit level.

Data from the fertility test showed that mean disease incidence at 220 lb N/acre was 1.6 times higher than 150 lb N/ acre (Fig. 5). Mean disease incidence in the susceptible variety, Bengal was 2.75 times higher than in the moderately resistant variety, Jupiter. The two fertility levels showed no significant differences in yield or milling quality (data not shown). In 2013 although the environment seemed unfavorable for disease development with a wet and cool season, nitrogen had a major effect, increasing BPB disease incidence for both varieties (Bengal and Jupiter).

Seeding rate showed no substantial treatment effects on disease incidence, yield, or grain quality in Bengal. Disease incidence appeared higher with higher seeding rates in Jupiter which had a lower tiller capacity than Bengal. Therefore as plant populations increased, the plot density increased allowing the disease to spread from plant to plant (Fig. 6). The results in Jupiter are indicative of the possible effect of seeding rate on BPB disease severity depending on susceptibility and tillering capacity of a variety. The experiment will be repeated once more in 2014 as in 2013.

Preliminary tests of seed treatment for antibacterial activity on artificially inoculated seeds with *B. glumae* using ultraviolet light, microwave, household antimicrobial agents, hot water, freezing, an industrial sanitation chemical, plant extracts, competitor bacteria, silver, and copper compounds have been discouraging due to the negative effect on seed germination. However, a fermented plant extract and diluted vinegar coupled with heat appeared to reduce the disease (Fig. 7). Treatment combination of vinegar and heat lowered the disease considerably compared to the check. It was also better than the plant extract coupled with heat. More investigation on these treatments and others is ongoing.

SIGNIFICANCE OF FINDINGS

Bacterial panicle blight has been an important disease in Arkansas rice causing millions of dollars loss in 2010 and 2011. While the development of resistant cultivars will offer the best long-term control, short-term disease management options such as planting date, seeding rate, nitrogen input, water management, and seed treatment options need to be explored.

ACKNOWLEDGMENTS

Special appreciation is extended to the Rice Research and Extension Board for providing funding and support for these projects; to Rick Cartwright of University of Arkansas System Division of Agriculture and Don Groth of Louisiana State University for their technical help; Jarrod Hardke of University of Arkansas for reviewing the manuscript; Chris Henry and Merle Anders of University of Arkansas for their advice in setting up the water stress test.

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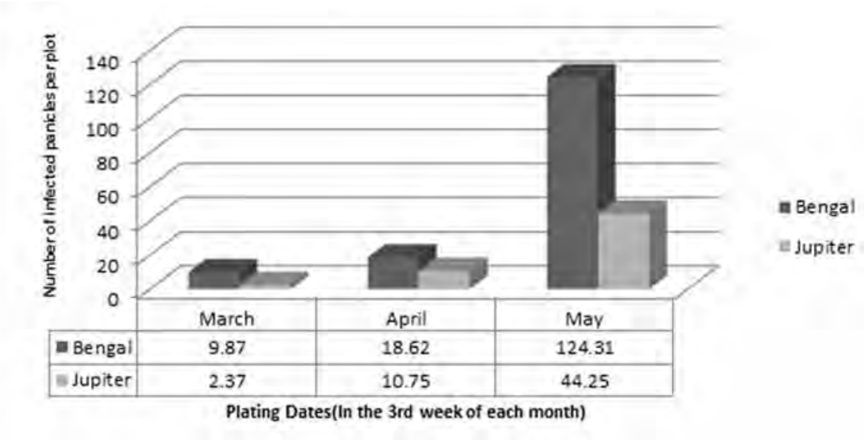


	March	April	May
■ Bengal	9.87	18.62	124.31
▨ Jupiter	2.37	10.75	44.25

Fig. 1. Effect of planting dates on severity of bacterial panicle blight, 2013.

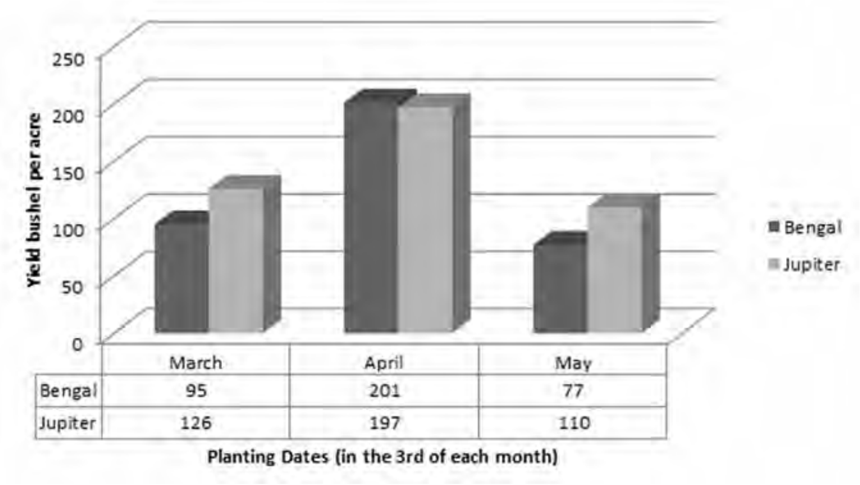


Fig. 2. Yield of Bengal and Jupiter at three planting dates from plots inoculated with bacterial panicle blight pathogen.

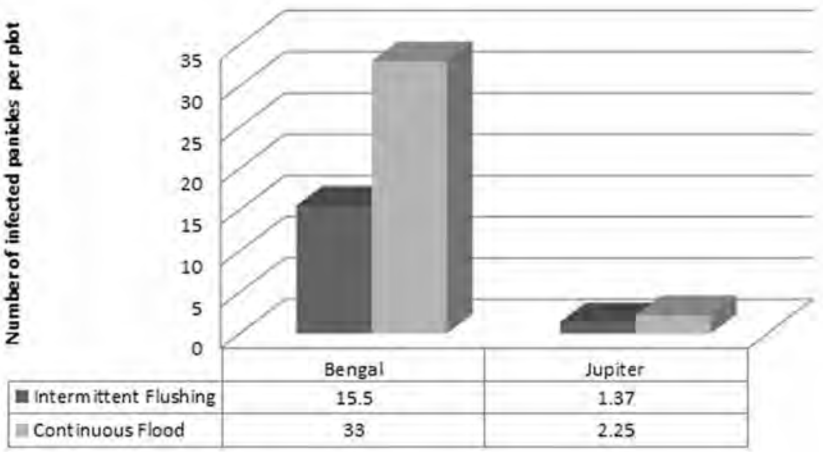


Fig. 3. Effect of water stress on bacterial panicle blight disease severity in 2013.

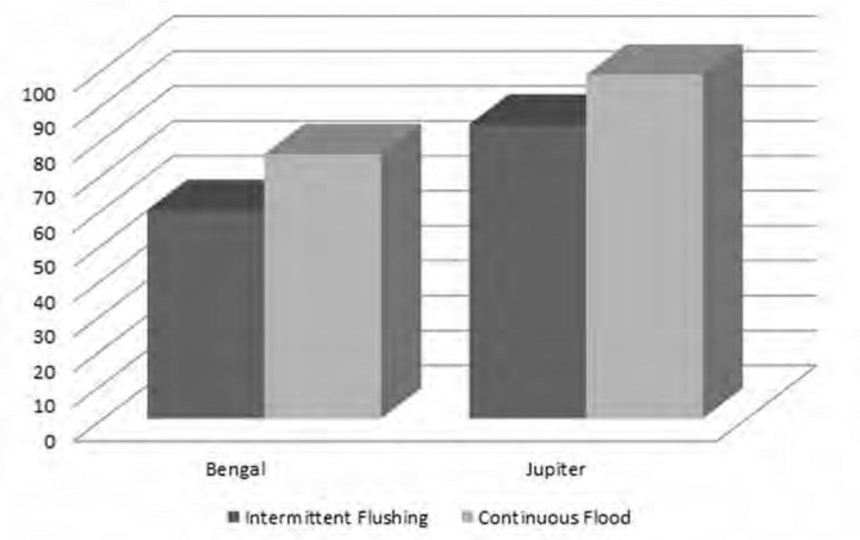
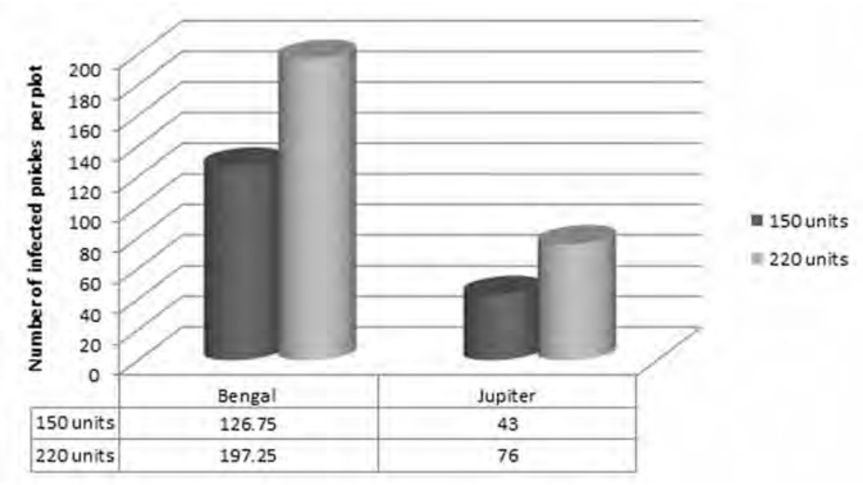
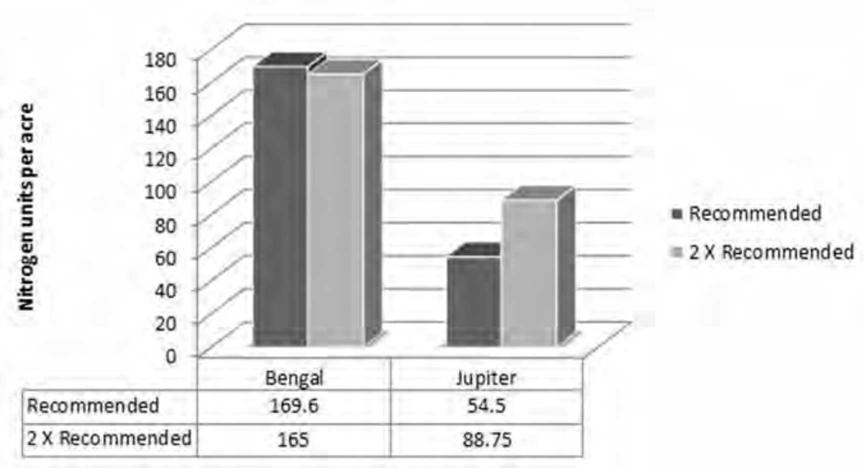


Fig. 4. Effect of water management on yield in 2013.



	Bengal	Jupiter
150 units	126.75	43
220 units	197.25	76

Fig. 5. Effect of nitrogen on bacterial panicle blight in 2013.



	Bengal	Jupiter
Recommended	169.6	54.5
2 X Recommended	165	88.75

Fig. 6. Effect of seeding rate on bacterial panicle blight severity on Bengal and Jupiter in 2013.

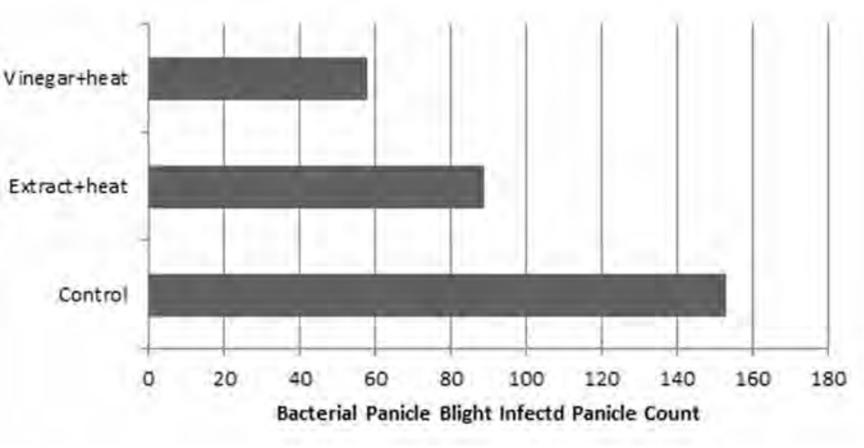


Fig. 7. Seed treatments tested in the field to suppress bacterial panicle blight disease in 2013.

Development of Practical Diagnostic Methods for Monitoring Rice Bacterial Panicle Blight Disease and Evaluation of Rice Germplasm for Resistance

Y. Wamishe, Y. Jia, M. Rasheed, C. Kelsey,
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ABSTRACT

A study was initiated to understand *Burkholderia glumae* (the major causal agent for bacterial panicle blight disease of rice); to develop practical diagnostic methods for monitoring the disease; and to evaluate rice germplasm for resistance. *B. glumae* was frequently isolated from symptomatic panicles on CCNT, a semi-selective medium. Selected isolates were assessed for virulence using hypersensitivity reaction on wild tobacco leaves and pathogenicity tests on rice seedlings. *B. glumae* isolates found to be hypersensitive on tobacco leaves and pathogenic on rice seedlings were used to inoculate rice in the greenhouse for bioassay studies and to screen germplasm for resistance in the field. The isolates were stored at -80 °C in 25% glycerol. In 2013, 196 Uniform Regional Rice Nursery (URRN) and 90 Arkansas Rice Performance Test (ARPT) entries were inoculated between boot-split to flowering growth stage of rice. Inoculation was done twice in an interval of 4 to 5 days. A 0 to 9 disease scoring scale was used where 0 showed no disease and 9 severe bacterial panicle blight. Of 286 entries, 15 entries showed no symptom of the disease and 53 entries showed moderate resistance with a rating of 1 to 5. The remaining entries rated between 6 and 9 and were grouped as moderately susceptible to very susceptible. The cutoff point between moderately resistant and moderately susceptible was based on the reaction of the known moderately resistant Jupiter variety that rated 5 for disease. None of the greenhouse seedling inoculations were definitive enough to separate relative resistance levels among the varieties tested. Detached leaf inoculation are being modified and tested in search of a technique that provides consistent resistance or susceptibility reaction among varieties. Additional tests to enable the search for molecular markers will continue for one more year.

INTRODUCTION

Bacterial panicle blight (BPB) of rice has been observed for many years in Arkansas and other southern rice-producing areas of the United States (U.S.) as a disorder of unknown cause. The disease was not considered to be a major problem until severe damage on Bengal in the mid-1990s. In 1996-97 it was discovered at Louisiana State University that *Burkholderia glumae* (formerly known as *Pseudomonas glumae*) was the major biotic agent causing BPB disease of rice. The disease has been observed increasing in rice production fields in Arkansas and other southern rice-producing states since 1995 and was so severe in 2010 and 2011 that it caused up to 50% yield loss in susceptible varieties (Cartwright, pers. comm.). Although *B. glumae* is the major species of bacteria frequently isolated from symptomatic rice panicles, the disease can be caused by more than one species of bacteria with different and/or overlapping habits. For instance, *B. glumae* is mainly seedborne while other bacteria are seedborne and residue-borne. The complexity of the bacterial species and their habits could contribute to the difficulty in managing BPB.

So far, there are no dependable cultural management options to reduce the disease. It has been observed that fields having received less applied nitrogen had reduced incidence of BPB and studies are ongoing to confirm this observation. Preliminary data from 2012 and 2013 field tests showed that water stress (shortage) had a greater negative impact on yield than BPB. Ongoing study on planting dates has indicated little to no symptoms of the BPB disease in March and April planted rice compared with late- May planted rice. The disease seems to favor extended hot summer nights; however, the role of other weather factors that encourage bacterial activity remain unclear. Fields cropped to continuous rice appear to have more severe disease symptoms. Overall, disease occurrence appears unpredictable due to insufficient information on the effect of crop rotation, the extent of bacterial survival in soil or on crop residues, and favorable weather conditions.

The disease cycle for BPB is not fully understood and chemical control options used in Asia have not been registered in the U.S. Current fungicides used on rice in the U.S. have no activity on bacterial panicle blight. Development of antibiotic resistance in Asia to natural products has raised concern about their successful use here. The ultimate solution to manage BPB would be the use of resistant varieties. Therefore, the objectives of this study were to (1) understand the biology of the bacteria that cause BPB; (2) develop suitable methods for screening and selecting resistant germplasm in the field, greenhouse and laboratory; and (3) identify rice lines with reliable genetic resistance for use in breeding programs.

PROCEDURES

B. glumae was isolated from symptomatic kernels collected from rice florets in the 2011 and 2012 crop seasons on CCNT agar medium. The CCNT agar is a partial selective medium containing 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 adjusted to pH 4.8. Only the isolates that produced yellow pigment diffused in CCNT agar medium and which tested positive for hypersensitivity on wild tobacco (*Nicotania rustica*) and pathogenicity on rice seedlings were selected for use. More collection and isolation was also carried out in 2013 from a rice breeder's field at the University of Arkansas System Division of Agriculture Rice Research and Extension Center (RREC) near Stuttgart, Ark. Yellow pigment that diffuses in the CCNT agar is a characteristic toxin produced by *B. glumae*. Pure isolates were stored at -80 ºC in 25% glycerol. Four isolates (#3, 28, 32, and 32) were equally combined in a mixture to create a stock bacterial suspension that was then used to streak King's B medium for greenhouse and field inoculations.

Evaluation of greenhouse and laboratory inoculation methods to identify levels of resistance to BPB have included: spraying, injecting, dipping, toothpick transfer, direct agar-plug contact with detached leaf or stem base, tissue cutting/wounding, soil inoculation with a bacterial suspension, and vacuum infiltration of the bacterium in seeds. Three 6-week-old seedlings were tested with needle and spray inoculation; whereas three 4-week-old seedlings were used for other tests. Spray inoculation on three 3-week-old seedlings was also tested. The rice varieties Bengal (susceptible variety) and Jupiter (moderately resistant) were used in all tests. Duplicate sets of the varieties were prepared and one set was kept in a humidity chamber for 12 h to maintain high humidity; whereas the other set was left on the greenhouse bench. To minimize the effect of ultraviolet light, spraying was done after dark. Germinated seeds were also transferred to soil infested with a bacterial suspension to detect seed and seedling rot.

Due to the inconsistency of agar plug contact on a punctured mid rib, the detached leaf inoculation method using a cotton swab was developed in 2013. A detached leaf was wounded by shallow-pricking the mid-rib with a 12 gauge sterile insulin syringe. The punctures were done gently not to break through the mid rib. The number of holes varied from one to five. The bacterial concentrations (~10^6 to 10^9 cfu/ml; colony forming units per ml) applied to the cotton swabs varied from 300 to 500 ml. The detached leaf wounding inoculation using cotton swab inoculation was also tested in different media. The media included moist Whatman filter paper (diam. = 9.0 cm), CCNT, PDA, and Oatmeal agar. Incubation included 30 °C in dark and room temperature. To minimize contamination, leaves were sterilized using a 1% solution of sodium hypochlorite for 3 minutes.

To screen rice germplasm for BPB resistance, 200 URRN (Uniform Regional Rice Nursery) and 90 ARPT (Arkansas Rice Performance Test) entries were planted in fields at the RREC near Stuttgart, Ark. Four entries from the URRN either were missing or failed to germinate. Five sets of these entries were planted: two on 22 April and three on 22 May in a row plot of 5 feet. One set from each planting date was spray-inoculated two consecutive times and flagged between boot-split and early flowering. *B. glumae* was grown on petri dishes of King's B medium, a non-selective medium, at 39 °C. A 24- to 48-h old *B. glumae* culture was washed with 10 ml of water and mixed in 1.5 liters of water. The solution was slowly stirred using a magnetic mixer for 30 minutes before using a backpack sprayer (Solo, Newport News, Va.) to apply a bacterial suspension of

~10^6 to 10^8 cfu/ml following the procedure adopted from LSU (Groth, pers. comm.). During the inoculation period, growth stage of the entries was checked twice weekly. Disease data were recorded three weeks after the last inoculation using a 0 to 9 scale, where 0 is no disease and 9 is severe disease. A set from each planting date was kept non-inoculated to serve as a control and was rated for natural BPB disease.

RESULTS AND DISCUSSION

Seedling spray inoculation in the dark did not produce any symptoms. Lesion sizes using agar plug contact inoculation were erratic from experiment to experiment and among varieties. Among the inoculation methods tested in the greenhouse and laboratory, wounded detached leaf inoculation using a cotton swab immersed in a bacterial suspension appeared the most promising. Jupiter and Bengal have shown measurable differences in their reaction with this method. Incubation of inoculated detached leaves in PDA and Oatmeal media encouraged growth of common contaminant fungi so symptoms were obscured. The acidity in CCNT medium yellowed the leaves faster than the other media. Leaf sterilization using a 1% solution of sodium hypochlorite for 3 minutes resulted in loss of chlorophyll faster than non-sterilized leaves. Incubating the inoculated detached leaves using sterilized-wet Whatman filter paper showed no contaminant fungi and disease symptoms were better defined. Using filter paper incubation a distinct water soaked area delimited by necrosis was repeatedly observed in Jupiter. The water soaked area in Bengal appeared wider and longer without a necrotic boundary. In some tests Jupiter showed a relatively shorter bacterial soaked area compared to Bengal. Tests are ongoing adjusting possible factors that result in variations until consistent results showing a differential disease reaction are obtained. Dark incubation at 30 °C appeared to give better results than room temperature, because *B. glumae* tolerates a higher temperature. The tests will be repeated adjusting the plant and leaf ages. When successful, the search for RNA expression markers will follow.

Stock suspension of *B. glumae* from four isolates created bacterial suspension that produced adequate symptoms of BPB in the field in 2013. Symptoms developed better in the April planted sets of the URRN and ARPT than in the May planted set. Although better disease development occurred with the earlier planting, this result was unexpected and possibly occurred due to the cold and wet conditions at the beginning of the season. For the 2012 season, hot and dry conditions prevailed and the late planting appeared to favor BPB disease development. BPB disease development was not present on most late maturing cultivars which were indicative of "disease escape" instead of resistance.

Using a 0 to 9 scale, where 0 is no infection and 9 is severe BPB, 15 entries were identified with no disease symptoms out of 286 entries from the artificially inoculated URRN and ARPT studies; hence, they were rated as highly resistant. Fifty three entries that rated 1 to 5 were grouped as moderately resistant (Figs. 1, 2, Table 1). The rest of the entries rated 6 to 9 and were grouped from moderately susceptible to very susceptible. The susceptible control Bengal consistently rated 8 and the known moderately resistant variety, Jupiter rated 5. Thirteen of the entries in ARPT that rated resistant to moderately resistant were subsets in the URRN and ARPT. Overall, from one season of testing, 68 of 290 entries showed promising resistance level to BPB disease.

SIGNIFICANCE OF FINDINGS

Plant resistance to BPB would provide long-term control in years of increased disease pressure compared to susceptible plants and thus improve yields. Developing effective resistance screening techniques for discovery of durable resistance in high yielding rice cultivars is a priority in a disease management strategy. The general objective of this project is to identify practical diagnostic methods for screening resistance and monitoring rice bacterial panicle blight disease. This will enable identification of more resistance genes to control the disease and transfer them into new and high yielding cultivars.

ACKNOWLEDGMENTS

The support of extension rice pathology research by the Arkansas Rice Research and Promotion Board is highly appreciated. We are grateful to Rick Cartwright of University of Arkansas System Division of Agriculture for his technical help, Don Groth of Louisiana State University, and Karen Moldenhauer of University of Arkansas for their collaboration. We appreciate USDA Agricultural Research Service Dale Bumpers National Rice Research Center for continued cooperation.

Table 1. Resistant and moderately resistant entries from Arkansas Rice Performance Test (ARPT) and Uniform Regional Rice Nursery (URRN) to bacterial panicle blight (BPB) disease of rice rated after artificial inoculation at Rice Research and Extension Center near Stuttgart, Ark.

ARPT 2013 R- MR[a] for BPB at RREC			URRN 2013 R-MR[a] for BPB at RREC		
Entry #	Accession	BPB Rate[b]	Entry #	Accession	BPB Rate[b]
285	341A/370R	0	199	RU0603075	0
248	RU1201050[c]	0	50	RU1201050[c]	0
250	RU1301105[c]	0	25	RU1202025	0
258	STG08P-09-112	0	147	RU1203147	0
257	STG09L-20-073	0	105	RU1301105[c]	0
219	RT CLXL745	2	182	RU1301182	0
220	RT XL723	2	94	RU1302094	0
267	RU1301099	2	125	RU1302125	0
230	SGT10IMI-01-216	2	194	RU1304194	0
284	805s/370R	3	196	RU1304196	0
278	810-1S/378R	3	198	RU1304198	0
246	RU1201004	3	155	RU1305155	0
280	RU1201179	3	34	RU1102034	2
271	STG10PR-04-073	3	2	RU1202082	2
233	STG11IMI-07-038	3	99	RU1301099	2
205	Taggart	3	11	RU1302011	2
283	810-1S/370R	4	85	RU1302085	2
203	Mermentau	4	138	RU1303138	2
218	RT CLXL729	4	56	Taggart	2
251	RU0801081	4	9	RU0903141	3
253	RU1301087	4	75	RU0903190	3
286	RU1301185	4	104	RU1103104	3
252	STG09L-21-199	4	4	RU1201004	3
210	Jupiter	5	24	RU1201024	3
221	RT XL753	5	10	RU1201027	3
242	RU1201047	5	179	RU1201179	3
243	RU1201061	5	22	RU1202131	3
261	RU1301102	5	190	RU1203190	3
260	STG07P-20-029	5	74	RU1204196	3
255	STG10P-12-109	5	145	RU1301145	3
263	STG10P-24-128	5	176	RU1301176	3
234	STG11IMI-06-130	5	115	RU1302115	3
227	STG11IMI-10-181	5	137	RU1302137	3
Check	Bengal	8	126	RU1303126	3
			193	RU1304193	3
			1	RU1305001	3
			160	Templeton	3
			20	Mermentau	4
			7	RU0801081	4
			113	RU1003113	4
			3	RU1003178	4
			87	RU1301087	4
			148	RU1301148	4
			82	RU1302082	4
			131	RU1302131	4
			140	RU1302140	4

continued

Table 1. Continued.

ARPT 2013 R- MR[a] for BPB at RREC			URRN 2013 R-MR[a] for BPB at RREC		
Entry #	Accession	BPB Rate[b]	Entry #	Accession	BPB Rate[b]
			19	RU9903092	4
			37	Jupiter	5
			123	RU1003123	5
			47	RU1201047	5
			61	RU1201061	5
			102	RU1301102	5
			185	RU1301185	5
			31	RU1302031	5
			106	RU1302106	5
			153	RU1303153	5
			Check	Bengal	8

[a] R = resistant, MR = moderately resistant.

[b] Disease rating scale where 0 = no disease, 9 = severe BPB disease.

[c] Entries present in both ARPT and URRN.

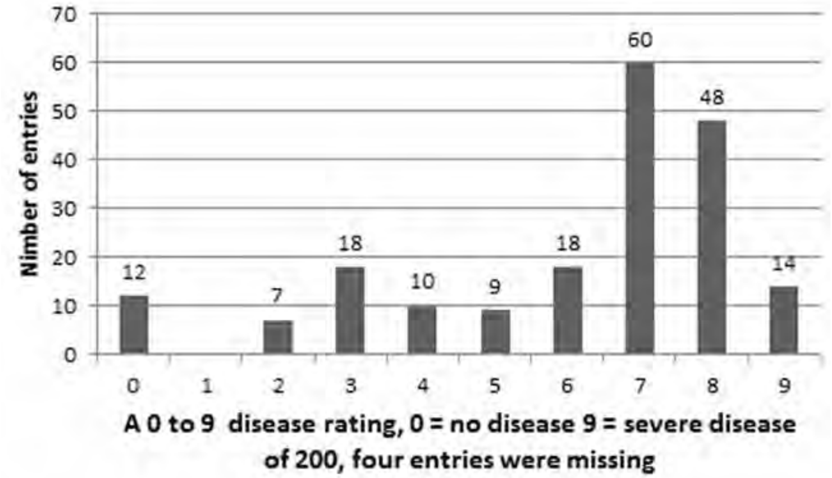

Fig. 1. Evaluation of 196 Uniform Regional Rice Nursery entries for bacterial panicle blight by artificial inoculation.

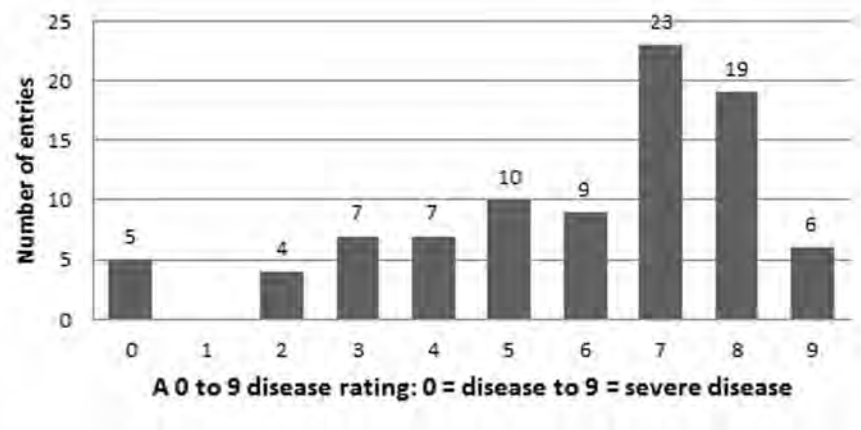

Fig. 2. Evaluation of 90 Arkansas Rice Performance Test entries for bacterial panicle blight using artificial inoculation, 2013.

The Interaction Between Nitrogen Fertilizer Rate and Insecticide Seed Treatment for the Control of Rice Water Weevil

M.E. Everett, G.M. Lorenz III, N.A. Slaton,
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ABSTRACT

Insecticide seed treatments have become the preferred method of control for the most injurious pest of rice (*Oryza sativa* L.), the rice water weevil (*Lissorhoptrus oryzophilus*, RWW). The benefits associated with insecticide seed treatments are well documented, but there have been instances where these treatments have not performed as expected and significant rice water weevil damage has occurred. Rice plants are highly dependent on the uptake of adequate nitrogen (N) for vigorous growth and the production of high yields in most fields and could influence insecticide seed treatment performance. Four trials were conducted in 2013 at the University of Arkansas System Division of Agriculture Pine Tree Research Station (PTRS), near Colt, Ark., and the University of Arkansas System Division of Agriculture Rice Research and Extension Center (RREC) near Stuttgart, Ark., to examine rice growth and insect population responses to different insecticide seed treatment and N rate combinations. Insecticide seed treatments included label rates of clothianidin (NipsIt INSIDE 5FS®), thiamethoxam (CruiserMaxx Rice 5FS™), and an untreated (fungicide only) control. Nitrogen was applied at 0, 45, 90, 135, and 180 lb urea-N/acre to rice plots. Rice seed treated with CruiserMaxx and NipsIt INSIDE sometimes enhanced stand density and grain yield while consistently reducing rice water weevil larval density. The results also suggest that urea-N rate does not influence insecticide efficacy, but does influence RWW larval density and grain yield.

INTRODUCTION

The rice water weevil (RWW), *Lissorhoptrus oryzophilus*, has long been considered as the most ubiquitous and injurious pest to rice (*Oryza sativa* L.) crops in most rice-producing areas of the world. Adult RWWs are attracted to open water and begin infesting rice fields once the permanent flood is established (Lorenz and Hardke, 2013). Female RWWs lay eggs vertically in the leaf sheath, just below the water's surface (Saito et al., 2005). Eggs hatch around eight days later, and the legless grubs soon chew through the leaf sheath, sink to the soil, burrow in the mud, and arrive at their true feeding site, the rice root system. Rice water weevil larvae prune the roots when feeding, decreasing the plant's ability to absorb nutrients and anchor the plant in the flooded soil. If the root system is severely damaged, the plant may become completely dislodged from the soil or demonstrate signs of nutrient deficiency such as yellowing, stunting, and slowed development (Lorenz and Hardke, 2013). Because of the rising cost of irrigation and the expense and unpredictability associated with foliar application of insecticide for RWW control, many producers have replaced their old pest management practices with more reliable insecticide seed treatments (Lorenz et al., 2011).

A number of insecticide seed treatment options are available to producers, and rice seed treated with these insecticides generally exhibits increased seedling vigor, increased yield, and decreased RWW damage. However, there have been instances where the selected insecticide seed treatment did not perform as expected. It is believed that soil fertility, nitrogen (N) in particular, may be a contributing factor to these occurrences. Research has been documented concerning the individual influence of N-fertilizer management and insecticide seed treatments on rice. However, the relationship between N management and insecticide seed treatments is largely unknown. This study was conducted to investigate the interaction between N-fertilizer rate and insecticide seed treatments for insect control, rice growth, and grain yield.

PROCEDURES

Four trials were conducted during 2013 to determine the interaction between N rate and insecticide seed treatments on seedling density, RWW larvae population, and rice grain yield. Two trials were conducted at the Pine Tree Research Station (PTRS), near Colt, Ark., and established on either Calloway or Calhoun silt loam soils following soybeans (*Glycine max*) in the rotation. Two additional trials were conducted at the Rice Research and Extension Center (RREC), Stuttgart, Ark., on a Dewitt silt loam soil, which also followed soybeans in the rotation.

The rice variety CL152 was planted on 28 March at RREC-1, 16 April at PTRS-1 and RREC-2, and 30 April at PTRS-2, into conventionally tilled seedbeds at 60 lb/acre. Each plot was 16-ft long and contained 9 rice rows (7-inch row spacings). Seed treatments were thiamethoxam (CruiserMaxx Rice 5FS™) at 7 oz/cwt and clothianidin

(NipsIt INSIDE® 5FS) at 1.92 oz/cwt, as well as an untreated (fungicide only) control. All seed received the same fungicide treatment which included 0.365 oz/cwt of Apron, 0.046 oz/cwt of Maxim, and 1 oz/cwt of Dynasty. Rice plants emerged on 16 April at RREC-1, 30 April at RREC-2, 3 May at PTRS-1, and 12 May at PTRS-2. Urea-N was applied at 0, 45, 90, 135, and 180 lb urea-N/acre. The 45 and 90 lb urea-N/acre rates were applied as a single application onto dry soil at the 4- to 5-lf stage. The 135 and 180 lb urea-N/acre rates were applied in two split applications where 90 and 135 lb urea-N/acre was applied to a dry soil surface at the 4- to 5-lf stage and followed by 45 lb urea-N/acre application between panicle initiation and differentiation. The permanent flood was established within two days after the preflood N was applied.

Plant density was measured at the 2- and 3-lf stages as proxies for seedling vigor. Stand counts were taken from a 10-ft section of an inner row of each plot. Rice water weevil larval density was evaluated by taking three soil core samples from each plot 21 days after flooding. Each soil core was taken with a four-inch diameter sampler, placed in a labeled sealable bag, stored on ice, and transported to the entomology laboratory at the University of Arkansas System Division of Agriculture Lonoke Extension Center in Lonoke, Ark. All soil cores were washed over a 40-mesh sieve to remove larvae and excess soil from the roots. The sieve was then immersed in warm salt water which caused the larvae to float to the top for counting. Grain was harvested from eight rows with a small plot combine, grain was weighed, grain moisture was determined, and grain yield was calculated and adjusted to 12% moisture for statistical analysis.

Each experiment was a randomized complete block (RCB, 4 blocks) design with a 3 (insecticide seed treatments) × 5 (total-N rates) factorial treatment structure. Stand density data using measurements from all plots were analyzed as a RCB comparing the three insecticide seed treatments since N fertilizer had not yet been applied when stand density measurements were collected. For the average number of rice water weevil larvae per core, only four preflood rates were used in the ANOVA with the 90 lb urea-N/acre rate means having eight observations and all other N-rate means having four observations. For all measurements, analysis of variance was performed by site using SAS v. 9.2 (SAS Institute; Cary, N.C.). Results were interpreted as significant at the 0.05 level. When appropriate, means were separated using Fisher's Protected Least Significant Difference (LSD) test.

RESULTS AND DISCUSSION

Stand Density

Stand density at the 2- and 3-lf stages was different among seed treatments only at the PTRS-2 and RREC-2 (Table 1). Both CruiserMaxx and NipsIt INSIDE treated rice resulted in denser stands than rice receiving no insecticide at PTRS-2 and RREC-2 at the 2-lf stage and also at RREC-2 at the 3-lf stage. For these environments and growth stages, the insecticide seed treatments produced similar stand densities. At the 3-lf stage at PTRS-2, rice treated with NipsIt INSIDE resulted in the highest stand density, while rice receiving no insecticide and rice treated with CruiserMaxx produced similar stand densities, which were lower than rice treated with NipsIt INSIDE. Stand density means at both the 2- and 3-lf stages exceeded the minimum recommended density for conventional varieties of 30 seeds/ft^2 (Wilson et al., 2013). The results suggest that the use of CruiserMaxx and NipsIt INSIDE can sometimes increase stand density.

Rice Water Weevil

The number of RWW larvae found in the rice root system was affected only by the main effects of preflood-N rate, averaged across insecticide seed treatments, and insecticide seed treatment, averaged across preflood-N rates, at PTRS-1, PTRS-2, RREC-1, and RREC-2 (Table 2). For these sites, the main effects showed that the average number of larvae was greater for rice that received no insecticide than rice seed that was treated with CruiserMaxx or NipsIt INSIDE which usually had similar numbers of larvae. The exception was RREC-2 where rice treated with NipsIt INSIDE had lower numbers of larvae than rice treated with CruiserMaxx. Likewise, the main effect of N rate showed that, compared to the no-N control, larvae numbers were usually greater when N fertilizer was applied, but the number of larvae was usually consistent among preflood-N rates.

At PTRS-1 the interaction between preflood-N rate and insecticide seed treatment was significant and, in general, showed similar overall trends as that described for the main effects at PTRS-2, RREC-1, and RREC-2 (Table 3). Rice plants receiving an insecticide seed treatment resulted in lower larval densities than rice that received no insecticide. All three seed treatments tended to have the lowest number of RWW larvae when no N was applied. The interaction was significant at PTRS-1 because the average number of rice water weevil larvae per core was consistent across N rates for rice treated with NipsIt INSIDE and CruiserMaxx.

Grain Yield

The insecticide seed treatment by N-rate interaction was not significant for any of the four experiments conducted in 2013. Grain yield at PTRS-1 and RREC-2 was affected by insecticide seed treatment (Table 4). Rice receiving an insecticide seed treatment resulted in greater yields than rice receiving no insecticide at PTRS-1 and RREC-2. CruiserMaxx and NipsIt INSIDE differed from each other only by 2 and 3 bu/acre at PTRS-1 and RREC-2, respectively. At both locations, rice treated with an insecticide seed treatment resulted in an average grain yield increase of 10 bu/acre when compared to rice that received no insecticide. Grain yields from rice treated with an insecticide seed treatment were not significantly different from rice receiving no insecticide at PTRS-2 and RREC-1.

Grain yield at all four sites was significantly affected by the total amount of N applied (Table 4). In general, yield increased numerically and oftentimes significantly with each incremental increase in N rate. The PTRS-2 location had the greatest numerical grain yield when no N was applied and maximal grain yields were produced by 135 lb N/acre suggesting that native soil N availability was greater at this site. For the other three sites, maximum grain yield was produced by application of the greatest N rate, 180 lb urea-N/acre which produced yields 14 to 45 bu/acre more than the rice fertilized with 135 lb N/acre.

SIGNIFICANCE OF FINDINGS

Rice seed treated with CruiserMaxx and NipsIt INSIDE had fewer RWW larvae compared to rice that received no insecticide. Plant tissue analysis results were not yet available to determine if insecticide seed treatment influenced fertilizer-N recovery. Results from 2013 indicate that insecticide seed treatments sometimes enhance stand density and grain yield while consistently reducing RWW larval density. The results also suggest that urea-N rate does not influence insecticide efficacy, but urea-N rate does influence RWW larval density and grain yield.

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Table 1. Stand density at the 2-lf stage or the 3-lf stage as affected by insecticide seed treatment (IST), for four experiments conducted in 2013 at the Rice Research and Extension Center (RREC) and Pine Tree Research Station (PTRS).

	2-lf stage				3-lf stage			
IST	PTRS-1	PTRS-2	RREC-1	RREC-2	PTRS-1	PTRS-2	RREC-1	RREC-2
	(no. seedlings/ft^2)							
UTC	42.4 a[†]	60.9 a	65.9 a	43.6 a	67.8 a	61.9 a	108.3 a	77.4 a
NipsIt	43.1 a	68.4 b	66.9 a	52.8 b	66.2 a	68.8 b	107.5 a	84.4 b
Cruiser	46.0 a	67.3 b	66.2 a	50.7 b	67.7 a	61.9 a	106.7 a	88.9 b

[†] Within each column (Site) means are statistically similar when followed by the same letter or different when followed by a different letter.

Table 2. The average number of rice water weevil (RWW) larvae per core as affected by insecticide seed treatment (IST), averaged across nitrogen rate (NR), or NR averaged across IST, for four experiments (analyzed by site) conducted in 2013 at the Rice Research and Extension Center (RREC) and Pine Tree Research Station (PTRS).

		Site			
Main effect	Treatment	PTRS-1[†]	PTRS-2	RREC-1	RREC-2
		(RWW larvae/core)			
IST	UTC	14.0 a[‡]	11.8 a	7.4 a	4.9 a
	NipsIt INSIDE	3.8 b	5.4 b	4.0 b	1.5 c
	CruiserMaxx	5.2 b	7.6 b	4.9 b	2.9 b
	(lb urea-N/acre)				
NR	0	4.6 a	6.3 a	3.0 a	1.8 a
	45	8.3 b	8.7 ab	5.7 b	2.5 ab
	90	9.0 b	9.1 b	6.4 b	3.6 c
	135	8.8 b	9.0 b	6.6 b	4.6 c

[†] The IST by NR interaction was significant at PTRS-1 and is shown in Table 3.

[‡] For each main effect and within each column (Site), means are statistically similar when followed by the same letter or different when followed by a different letter.

Table 3. The average number of rice water weevil (RWW) larvae per core as affected by the interaction between insecticide seed treatment (IST) and nitrogen rate (NR) for an experiment conducted in 2013 at the Pine Tree Research Station (PTRS-1).

		IST	
NR	UTC	NipsIt INSIDE	CruiserMaxx
(lb Urea-N/acre)		------------- (RWW larvae/core) ------------	
0[†]	7.8	3.3	2.5
45[‡,§]	13.7	3.7	7.6
90	18.1	3.3	5.6
135	16.5	4.7	5.3

[†] The $LSD_{0.05}$ to compare means of treatments receiving 0, 45, and 135 lb urea-N/acre is 5.1.

[‡] The $LSD_{0.05}$ to compare means among seed treatments that received 90 lb urea-N/acre is 3.6.

[§] The $LSD_{0.05}$ to compare means of treatments receiving 90 lb urea-N/acre to all other N rate means is 4.4.

Table 4. Rice grain yield means as affected by insecticide seed treatment (IST), averaged across N rates, or nitrogen rate (NR), averaged across insecticide seed treatments, for four experiments conducted in 2013 at the Rice Research and Extension Center (RREC) and Pine Tree Research Station (PTRS).

Main		Site			
effect	Treatment	PTRS-1	PTRS-2	RREC-1	RREC-2
		----------------------------(bu/acre[†])-----------------------------			
IST	UTC	163 a	198 a	137 a	157 a
	NipsIt INSIDE	172 b	200 a	142 a	165 b
	CruiserMaxx	175 b	198 a	146 a	167 b
	(lb urea-N/acre)				
NR	0	89 a	153 a	58 a	98 a
	45	142 b	188 b	92 b	124 b
	90	190 c	209 c	153 c	177 c
	135	208 d	220 d	181 d	194 d
	180	222 e	223 d	226 e	223 e

[†] For each main effect and within each column (Site), means are statistically similar when followed by the same letter or different when followed by a different letter.

PEST MANAGEMENT: INSECTS

The Role of Rice Stink Bug in the Transmission of Bacterial Panicle Blight in Rice

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ABSTRACT

Bacterial Panicle Blight (BPB) is a seed- and residue-borne disease caused by the pathogens *Burkholderia glumae* and *B. gladioli*. In recent years, the incidence and severity of BPB appears to be correlated with the increases in abundance of insect pests of rice in Arkansas, notably rice stink bug [*Oebalus pugnax* (F.); RSB]. The objective of this study was to investigate the extent to which the BPB pathogens were found associated with RSB in different locations throughout the state. Our analyses show that RSB populations are capable of harboring the BPB pathogens at a very low frequency. The presence of the pathogen in the gut but not on the exterior suggests that the pathogen may be a gut symbiont of BPB; bacteria in the genus *Burkholderia* are known symbionts in the gut of other hemipteran insects. While a pathogen detection rate of ~3% in the RSB may seem like a very small proportion (i.e., low vector potential of RSB), the high abundance of RSB across rice agroecosystems (typically in the order of millions of insects in any given location or year) means that this can still translate into high absolute numbers of RSB that carry the pathogen. To truly understand the risk of vectoring of BPB by RSB, the efficiency of transmission of this disease by RSB (i.e., vectorial capacity) needs to be evaluated.

INTRODUCTION

Bacterial Panicle Blight (BPB) is a seed- and residue-borne disease caused by the pathogens *Burkholderia glumae* and *B. gladioli*. In some years, BPB can be the most significant disease of rice in Arkansas and other rice-growing regions of the southern U.S., and is capable of reducing yields by 10% to 20% and affecting milling quality.

The pathogen overwinters in infected seed and crop residue in the soil and is capable of re-establishing populations on rice seedlings, and subsequently going on to impact yield and grain quality by infesting the panicles as the plant matures. The pathogen is transferred between plants in the field through the action of wind and rain, and this movement is localized. Agents of longer distance dispersal of the pathogen are poorly understood.

In recent years, the incidence and severity of BPB appears to be correlated with the increases in abundance of insect pests of rice in Arkansas, notably rice stink bug [*Oebalus pugnax* (F.); RSB]. This correlation could be equally explained by two possibilities: (a) environmental conditions that are favorable for the incidence of BPB are also the same ones that are suitable for rice insects, or (b) rice insect pests are an important vector of BPB either through incidental or vectored movement, and transmission of the bacterial pathogen between rice plants (such disease-vectoring is known in other stink bug species). If the former explanation is true, then management of BPB and rice insect pests can continue to be treated as independent pest pressures in rice production. However if the latter is true, then the management of both the bacterial disease and the impacts of rice insect pests may be contingent on the effectiveness of the management against insects. Understanding the role of insect pests in the transmission of BPB is therefore important in the context of facilitating effective management of both bacterial and insect pressures on rice production.

The objective of this study was to investigate the extent to which the BPB pathogen was found associated with RSB in different locations throughout the state.

PROCEDURES

Field Sampling

Rice stink bugs were collected using standard sweepnet-based sampling techniques from 27 grower fields (and associated field margins) across ten counties of Arkansas (Arkansas, Lonoke, Prairie, Chicot, Ashley, Desha, Mississippi, Clay, Jackson, and Poinsett counties), and from fields at the University of Arkansas System Division of Agriculture Rice Research and Extension Center (RREC) near Stuttgart, Ark., with a known presence of the BPB-causing pathogens (Table 1). The majority of the sampling was conducted when rice plants were at the milk to soft dough stages of panicle development, as this is the preferred feeding stage for RSB and therefore when disease transmission by RSB is most probable (Table 1). Field-collected insects were grouped by sampling location to avoid cross contamination of samples, and stored live in a cooler with ice for transport to the laboratory.

Laboratory Methods

The field-collected insects were held alive in a refrigerator in the laboratory prior to examining them for the presence of the BPB pathogen on their exterior surface and in their gut. In all, 565 individual RSB were examined for the presence of the BPB pathogen (Table 1). Two methods were used to detect the BPB pathogen. This included traditional diagnostics using a selective growth medium (CCNT) to culture and detect the BPB pathogens (Kawaradani et al., 2000), and a polymerase chain reaction (PCR)-based molecular diagnostic method that used *Burkholderia*-specific markers to detect the presence of the BPB pathogens (Maeda et al., 2006). Standard axenic protocols were followed in the handling of all samples, and included oven sterilization of all glassware at 130 °C for at least 20 minutes between each dissection and flame sterilization of all handling and dissection instruments to avoid cross-contamination.

Within one week of collection, the external surfaces (dorsal and ventral) of each insect were pressed onto the CCNT medium with a sterile pair of forceps. The CCNT plates were sealed with Parafilm immediately after the plating process, and incubated for 48 h at 39 °C. The presence of BPB in a plate is indicated by the presence of distinct yellow coloration that is the result of a reaction between the medium and toxins produced by the BPB pathogen (Kawaradani et al., 2000).

The exterior of each insect was then surface sterilized using a 2% sodium hypochlorite solution for one minute, and the insect was dissected in a sterile glass dissection Petri dish. The gut of the RSB has been characterized previously (Hamner, 1936), and contains four distinct gut sections and an elaborate salivary gland. The gut was examined for the presence of the BPB pathogens using either the CCNT medium or PCR-based analyses. The gut was aseptically removed, and each of the four gut sections from each insect was separately plated on the CCNT medium; alternatively, the entire gut was stored in a sterile tube at -20 °C for PCR-based analysis. The salivary gland is part of the first gut section, and wherever possible it was plated separately on the CCNT medium. The CCNT plates with the gut tissues were incubated, as described for the insect's external surface, to document the presence of the BPB pathogens.

Positive detection of the pathogen using molecular methods were done by examining the presence of DNA fragments of a specific size (597, 529, and 479 bp DNA fragments corresponding to the *gyrB* nucleotide sequences of *B. plantarii*, *B. glumae*, and *B. gladioli*, respectively) using gel electrophoresis (Maeda et al., 2006).

Positive controls using a pure culture of *B. glumae* were run for each batch of CCNT plates and PCR samples.

RESULTS AND DISCUSSION

None of the CCNT plates of the external surfaces of RSB tested positive for the presence of BPB. However of the 324 gut samples examined by the CCNT method, 9 tested positive for the presence of the BPB pathogens (Table 1). This represents ~3% of the processed samples. Among the positive samples, there was no clear association of a given gut section with the presence of the pathogen. All samples that tested positive were from fields with a known BPB history, suggesting that when the disease is present in the plant, RSB may be capable of acquiring it while feeding on an infected plant.

None of the PCR samples tested positive for the presence of the BPB pathogen. There are three plausible explanations for this: (a) the pathogen is not present in association with the RSB gut, (b) some aspect of our handling of the gut tissue is causing the pathogen to die prior to amplification by the PCR process, or (c) the amount of pathogen DNA in the insect tissue is below the detection threshold of the PCR-based method. Among these (b) and (c) are the most likely explanations, given our ability to detect the pathogen using the CCNT method. These aspects are topics of ongoing collaborations among the authors.

Our analyses show that RSB populations are capable of harboring the BPB pathogen(s) at a very low frequency. The presence of the pathogen in the gut but not on the exterior suggests that the pathogen may be a gut symbiont of RSB; bacteria in the genus *Burkholderia* are known symbionts in the gut of the other hemipteran insects (Kikuchi et al., 2008). Additional work, specifically tailoring of the PCR-based method for detection of the BPB pathogen in association with insect vs. plant tissues and at the soil-plant interface, is needed to better understand the transmission of this disease.

SIGNIFICANCE OF FINDINGS

While a pathogen detection rate of ~3% in the RSB may seem like a very small proportion (i.e., low vector potential of RSB), the high abundance of RSB across rice agroecosystems (typically in the order of millions of insects in any given location or year) means that this can still translate into tens of thousands of of RSB that carry the pathogen in a given field. To truly understand the risk of vectoring of BPB by RSB, the efficiency of transmission of this disease by RSB (i.e., vectorial capacity) needs to be evaluated. In addition, other closely related insects in the order Hemiptera need to be examined, and their vector potential and vectorial capacity in the context of BPB transmission needs to be evaluated.

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Table 1. Summary of origin and numbers of rice stink bug (RSB) dissected and examined using either a selective growth medium or polymerase chain reaction-based methods for the presence of the bacterial panicle blight (BPB)-causing pathogens.

Sample origin	Sample month	CCNT	PCR
Throughout the state	July	158	0
Throughout the state	October	34	89
From planting date trials at the RREC	August (March)[a]	0	12
	August (April)	12	20
	August (May)	12(1)[b]	12
	September (May)	12	12
	October (May)	12	12
RREC, inoculated plots[c]	August	48(4)	48
	September	24(4)	24
	October	12	12

[a] Planting date given in parentheses. Sampling was restricted to rice plants with panicles in the milk to soft dough stage, as this is the stage preferred by the rice stink bug.

[b] Numbers in parentheses indicate the number of insects that tested positive for the presence of BPB pathogens

[c] Data from the plots at the RREC that had plants that were seed and surface inoculated with the BPB pathogen.

Stored-Product Insects Associated with On-Farm Storage in Northeast Arkansas

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ABSTRACT

Integrated pest management (IPM) is important to reduce loss and damage to stored bulk rough rice. One component of IPM is to know how insect populations fluctuate over time. We therefore conducted a study from June to November, 2013 on four on-farm rice storage facilities in northeast Arkansas to examine the temporal and spatial distribution of stored-product insects. The warehouse beetle (*Trogoderma variabile*) and lesser grain borer (*Rhyzopertha dominica*) were the two most abundant beetles found at all locations. Indianmeal moths (*Plodia interpunctella*) and red flour beetles (*Tribolium castaneum*) were also present, but in lower numbers. Interestingly, stored-product insects were very abundant throughout the summer even when rice was not stored at these facilities.

INTRODUCTION

Once rice is stored in grain bins on farms or in commercialized storage facilities, the rice becomes very vulnerable to infestations of stored-product insects which can damage the kernels, reducing the economic value. One insect of importance to stored rice is the lesser grain borer, *Rhyzopertha dominica* (Potter, 1935). This insect is a primary feeder, exploiting whole kernels of grain by feeding and developing fully to adult within the kernel. Other insects, such as cigarette beetles (*Lasioderma serricorne*), red flour beetles (*Tribolium castaneum*), and Indianmeal moths (*Plodia interpunctella*), cannot exploit whole kernels and typically feed on broken kernels, those damaged by primary feeders (USDA, 1980). The larvae of warehouse beetles, *Trogoderma variabile*, will survive on a variety of food sources, including mixed animal feeds and processed grains such as polished rice (Partida and Strong, 1975). To reduce loss and damage to stored bulk rough rice, it is important to understand the spatial and movement patterns of these insects. To make good integrated pest management (IPM) decisions, one needs to know what species to target and when these populations occur. With the current lack of published data on insects associated with stored rice, the objective of this study was to document the species of stored-product insects associated with on-farm rice storage in northeast Arkansas. We also wanted to compare their temporal distributions with rice storage and management events.

PROCEDURES

Insects were collected from 18 June through 15 November 2013 at four on-farm storage facilities in Poinsett County in northeast Arkansas. There was variation in the design, the amount of rice stored, and insect control strategies among the facilities. Location A stored in total 75,000 bushels of rice in four bins. Bins ranged in size from 11,000 bushels to 24,000 bushels each. After harvest, rice was loaded in the bins starting 11 September and was completed 4 October 2013. Before rice was stored, all bins were treated with resmethrin. Rice was aerated using fans which were constantly running (except during heavy rains) until mid-November. Location B had five bins totaling 40,000 bushels with rice storage beginning in mid-September. Location C had a storage capacity of 137,500 bushels with five bins on the property. Location D had five bins totaling 50,000 bushels. Locations B thru D were all treated with diatomaceous earth (20-21 August 2013) before rice was added to the bins. Locations B and C were also treated with malathion on 12 September before rice was added. Locations B through D also used fans to aerate the rice and continuous aeration was used until temperatures dropped below 10 °C at night.

Five Delta glue traps (30.5 × 18.0 cm) (Scentry Biologicals Inc., Billings, Mont.) were hung on the exterior walls of the bins (~1.0 m to 1.5 m high) and retrieved each week to collect insects. Each Delta trap had a thin layer of glue (Bio-Quip Tangle-Trap®, Rancho Dominguez, Calif.) and was baited with four different Trécé® (Adair, Okla.) pheromone lures to attract the lesser grain borer, warehouse beetle, cigarette beetle, and Indianmeal moth. The lures were attached to the middle of each trap using a twist tie to ensure each pheromone would not dislodge. The lesser grain borer lures were replaced after four weeks in the field and the remaining lures were used for six consecutive weeks in the field. Ten Dome traps (Trécé, Inc., Adair, Okla.) were also placed at each facility to collect red flour beetles. Each Dome trap was baited with a red flour beetle pheromone lure, with lures replaced every eight weeks. To ensure Dome traps stayed in position, each trap was secured onto a metal holder (15 × 15 cm). Traps were collected each week until the end of October when traps were collected every two weeks. Hourly temperatures were recorded at each facility using a HOBO® ProV2 (Onset Computer Corporation, Bourne, Mass.). Data loggers were retrieved every second week and taken back to the lab where the data were downloaded. All stored-product insects were identified to species. Other insects were identified to family level.

RESULTS AND DISCUSSION

The warehouse beetle and lesser grain borer were the two most common beetles associated with on-farm rice storage (Fig. 1). Locations A and B had the most warehouse beetles collected with 1128 and 690 beetles, respectively. Warehouse beetles can be in large populations around grain facilities (Larson et al., 2008) and this beetle was the most common insect collected at a rice mill in northeast Arkansas (White, 2011). Location B had the most lesser grain borers collected with 691 insects (Fig. 1). Indianmeal moths and red flour beetles were also abundant but in lower numbers (Fig. 1). Interestingly, stored-product insects were present even when storage bins were empty (Fig. 2). For example, at location A, over 250 warehouse beetles were collected after the first week of the study. The population decreased into July, but started to increase into August with a peak at the end of August (Fig. 2A). This was similar to location D (Fig. 2B). The warehouse beetle populations seemed to decrease when rice was placed in the bins. Lesser grain borers seemed to have three population peaks between June and the beginning of September (Fig. 2). However, when rice was placed in the bins at the beginning of September, the population of lesser grain borers seemed to decrease at both locations A and D (Fig. 2). At location A, resmethrin was applied before rice was stored and this could have been the reason for the decrease. At location D, diatomaceous earth was applied 20-21 August. Lesser grain borers numbers were still on the increase until rice was placed in the bins (Fig. 2B). The population of lesser grain borers decreased until the end of September when the population started to increase again with a final peak in the second week of October (Fig. 2B). Very few Indianmeal moths were collected at location A while storage bins were empty. However, Indianmeal moths became more abundant when rice was placed in the bins (Fig. 2). This was evident for both locations. However, at location D, the Indianmeal moth population began increasing a bit earlier than location A (Fig. 2). Red flour beetle numbers were very low at all facilities (Fig. 1) with numbers increasing only slightly when rice was present (Fig. 2). In Fig. 3 we present temperature data from location D. Temperatures were similar for the other four locations. As temperatures decreased below 15 °C, there was a decrease in all of the stored-product insects (Figs. 2 and 3).

Other stored-product insects were collected. They included the broadnosed grain weevil (*Caulophilus oryzae*), rice weevils (*Sitophilus oryzae*), rusty grain beetles (*Cryptolestes ferrugineus*), the hairy fungus beetles (*Typhaea stercorea*), and the sawtoothed grain beetle (*Oryzaephilus surinamenis*) (Table 1). Booklice (*Psocoptera*) were also present. These insects have contributed to weight losses in rice (McFarlane, 1982) and wheat (Kučervoá, 2002) and need to be examined in greater detail around rice storage facilities.

SIGNIFICANCE OF FINDINGS

This study gives a new perspective in understanding the population dynamics of insects around on-farm storage facilities. Insects being present throughout the summer, even when rice is not stored, gives new insight into the amount of insect pressure these facilities can be under. Producers should be aware that IPM strategies should be implemented even when rice is not being stored on premise. Research on various insect control strategies before rice is stored is warranted.

ACKNOWLEDGMENTS

The authors thank the Arkansas Rice Research and Promotion Board for funding this project. We are also gratefully to the rice producers who allowed us access to their rice storage facilities.

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Table 1. Number of individuals collected per taxa from Dome traps between 18 June and 15 November 2013 from two on-farm storage facilities in northeast Arkansas.

		Location	
Taxon	Family	A	D
Coleoptera	Anobiidae[a]	1	0
	Anthicidae	2	1
	Bostrichidae[b]	0	4
	Carabidae[c]	14	9
	Chironimidae	13	54
	Chrysomelidae	3	5
	Cryptophagidae	0	2
	Curculionidae[d]	3	2
	Dermestidae[e]	3	2
	Elateridae	3	3
	Laemophloeidae[f]	3	0
	Mycetophagidae[g]	97	13
	Silvanidae[h]	1	0
	Staphylinidae	2	11
	Tenebrionidae	25	21
Hymenoptera	Braconidae	1	2
	Chalcidoidea	1	0
	Formicidae	84	7
Diptera	Culicidae	3	0
Heteroptera	Cicadellidae	1	0
	Miridae	1	2
Psocoptera	Liposcelididae[i]	104	28
Neuroptera	Chrysopidae	1	0
Araneae[j]		3	5

[a] Spider beetles.
[b] Lesser grain borers.
[c] Ground beetles.
[d] Broadnosed grain weevils and rice weevils.
[e] Warehouse beetles.
[f] Rusty grain beetles.
[g] Hairy fungus beetles.
[h] Sawtoothed grain beetle.
[I] Booklice.
[j] Spiders.

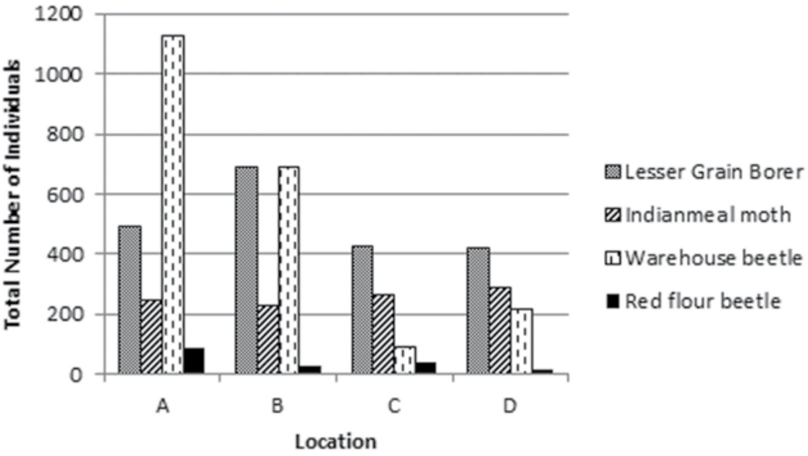

Fig. 1. Total number of stored-product insects collected using Delta traps between 18 June to 15 November 2013 from four on-farm storage facilities in northeast Arkansas.

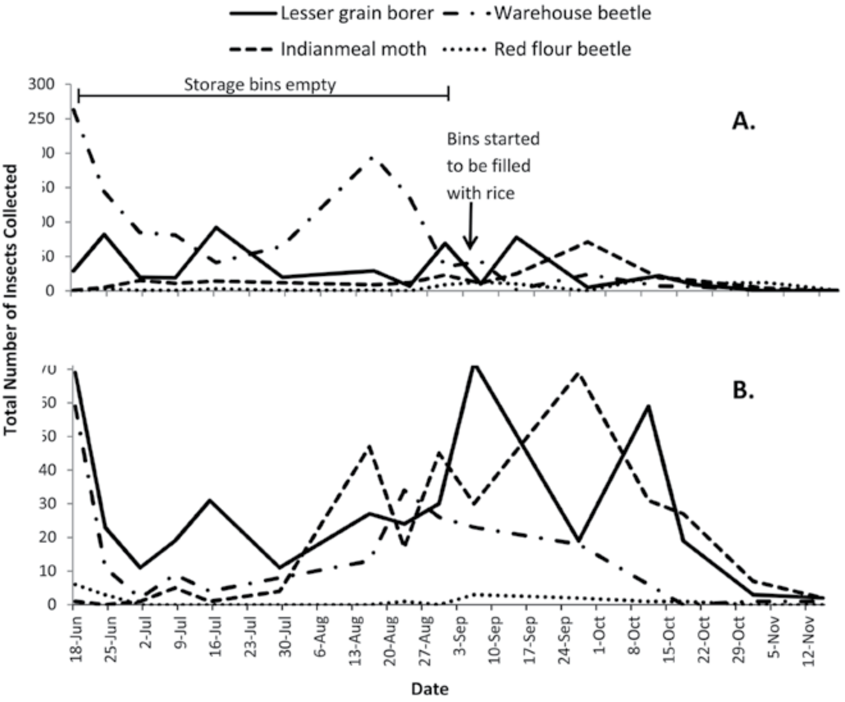

Fig. 2. Total number of lesser grain borer, warehouse beetle, Indianmeal moth, and red flour beetles collected from 18 June to 15 November 2013: A) location A, and B) location D, two on-farm rice storage facilities in northeast Arkansas.

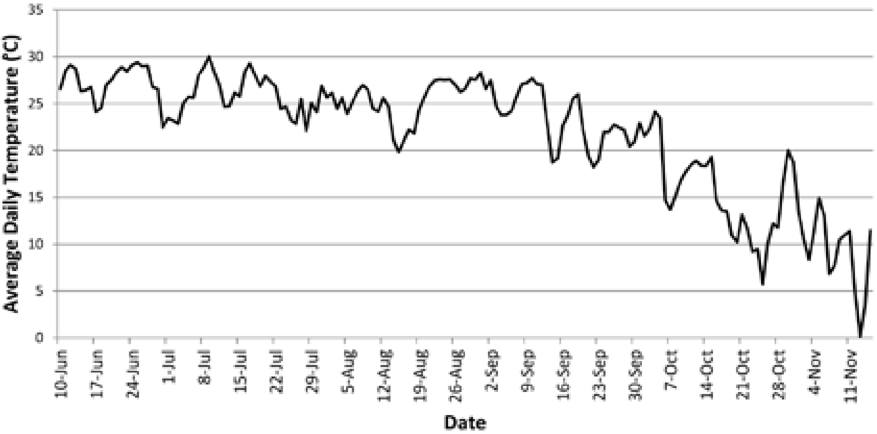

Fig. 3. Average daily temperatures at an on-farm rice storage facility (location D) in northeast Arkansas.

Efficacy of Selected Insecticides for Control of Rice Stink Bug, *Oebalus pugnax*, in Arkansas, 2013

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ABSTRACT

The rice stink bug, *Oebalus pugnax*, is one of the most destructive insect pests of rice production in the mid-South. A study was conducted in Faulkner County to determine the efficacy of selected compounds for control of the rice stink bug. Results from this study indicated that new insecticides may have potential value for control of stink bugs in rice.

INTRODUCTION

In Arkansas rice, the rice stink bug (RSB) is a common pest. This pest feeds on a large variety of wild hosts as well as several cultivated crops which allows for multiple generations each year (Lorenz and Hardke, 2013), In most cases RSB don't occur in rice fields until heading, but can occur earlier if wild hosts are present in or around field edges. The adults and nymphs have piercing-sucking mouthparts. When the RSB pierces the grain of rice, it forms a sheath that is visible from the outside of the grain which is called a feeding sheath. Rice stink bugs feed on developing kernels resulting in kernel shrinkage and yield loss. Infection by pathogens transmitted during feeding into the kernel cause discoloration which the rice industry categorizes as "pecky rice". (Johnson et al., 2002).

PROCEDURES

The site for this trial was located in Faulkner County. Plot size was 15 ft × 25 ft in a randomized complete block design with four replications. Foliar treatments included: Declare at 0.015 lb ai/acre, Declare at 0.02 lb ai/acre, Malathion 57% 1.25 lb ai/acre, Karate ZZ 2.56 oz/acre, CHA-3158 at 0.625 lb ai/acre, CHA-3158 at 1.25 lb ai/acre, CHA-3158 at 2.5 lb ai/acre, Endigo ZCX at 5 oz/acre, Tenchu at 9 oz wt/acre, Endigo ZCX at 6 oz/acre, and Centric 3.5 oz wt/acre. All treatments were compared to an untreated check (UTC). Insecticide treatments were applied with a hand boom on 31 July 2013. Insect ratings were taken 5 and 8 days days after treatment. The boom was fitted with TX6 hollow cone nozzles at 19-inch nozzle spacing, spray volume was 10 gal/acre at 40 psi. Insect density was determined by taking 10 sweeps per plot with a standard sweep net (15-inch diameter) and compared to the economic threshold of 5 rice stink bugs per 10 sweeps. Data was processed using Agriculture Research Manager v. 9, analysis of variance, and Duncan's New Multiple Range Test (P = 0.10) to separate means.

RESULTS AND DISCUSSION

Results indicated all treatments reduced RSB population below the UTC and only one application was needed to reduce numbers below threshold. At five days after application (5 DAT 1) Centric at 3.5 oz wt/acre reduced stink bug numbers better than all treatments, although it did not differ from Endigo ZCX at 6 oz/acre (Fig. 1). At eight days after application (8 DAT 1), all treatments reduced RSB below the UTC; however, Declare 0.02 lb ai/acre did not reduce RSB numbers below economic threshold (Fig. 2). Endigo ZCX at 6 oz/acre and Endigo ZCX at 5 oz/acre controlled RSB better than the other treatments, although it did not separate from Tenchu at 9 oz wt/acre, Karate Z at 2.56 oz/acre, Centric 3.5 oz wt/acre, and Malathion 57% 1.25 lb ai/acre.

SIGNIFICANCE OF FINDINGS

The rice stink bug causes poor milling and yield loss for Arkansas producers. The use of insecticides gives producers the ability to significantly lower rice stink bug numbers. When populations are at moderate levels, like in 2013, many compounds are able to reduce RSB below economic threshold with just a single application. Alternate insecticides such as Tenchu and Centric may help lessen the potential for increasing resistance to pyrethroids. New products allow use of multiple modes of action, increase residual control, reduce number of applications, have excellent control compared to currently labeled products, and may improve yield and quality of rice. The continued research of selected compounds is necessary for the control of the rice stink bug.

ACKNOWLEDGMENTS

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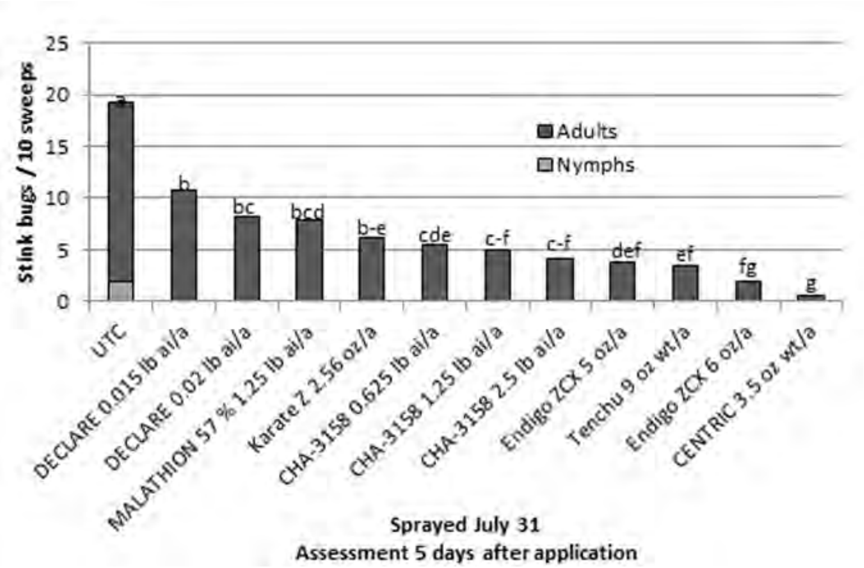

Fig. 1. Efficacy of selected insecticides for the control of rice stink bugs in Arkansas rice, 2013. Insect density determined by taking 10 sweeps per plot. Means followed by same letter do not significantly differ (*P* = 0.10, Duncan's New Multiple Range Test). Mean comparisons performed only when analysis of variance Treatment P (F) is significant at mean comparison Observed Significance Level.

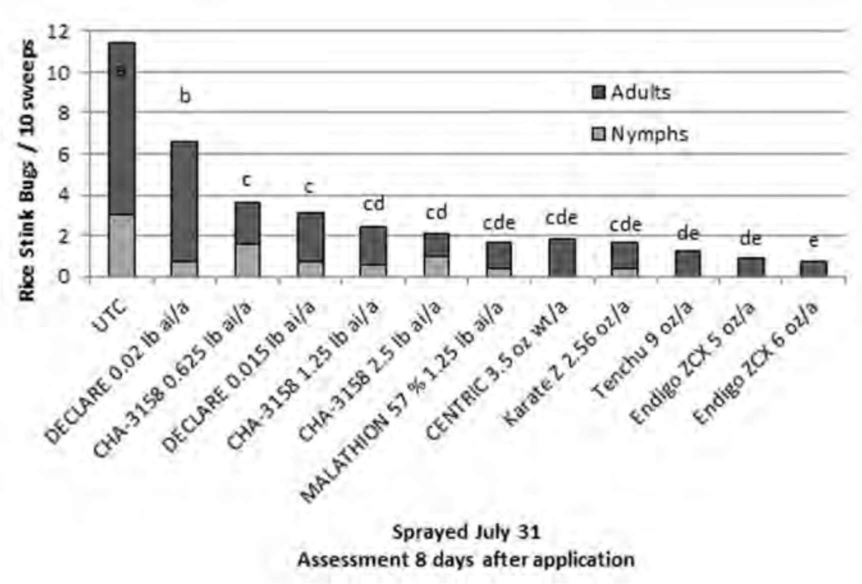

Fig. 2. Efficacy of selected insecticides for the control of rice stink bugs in Arkansas rice, 2013. Insect density determined by taking 10 sweeps per plot. Means followed by same letter do not significantly differ (*P* = 0.10, Duncan's New Multiple Range Test). Mean comparisons performed only when analysis of variance Treatment P (F) is significant at mean comparison Observed Significance Level.

A Historical Look at Rice Insecticide Seed Treatments from 2007 to 2013: Where Are We Now?

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ABSTRACT

The use of insecticide seed treatments (ISTs) for control of rice water weevil, *Lissorhoptrus oryzophilus*, and grape colaspis, *Colaspis brunnea*, by growers has increased rapidly since their introduction in 2007. The purpose of this paper is to give an overview of the work that was done to develop our knowledge base and recommendations for use by rice growers in Arkansas. The objectives of our trials were to evaluate the efficacy of selected insecticide seed treatments, find the correct rates of ISTs, evaluate new formulations, assess ISTs on different seeding rates and cultivars, as well as combining an IST and/or foliar applications. Our studies also indicated that ISTs can enhance plant stands and vigor as well as provide control of the rice water weevil and grape colaspis, subsequently resulting in increased yields for rice producers in Arkansas.

INTRODUCTION

In 2005 with the loss of Icon (fipronil) seed treatment, due to a voluntary withdrawal of the label by the company, rice growers had very few options for control of the major insect pests of rice, the grape colaspis (GC, *Colaspis brunnea*), referred to by many growers as the “lespedeza worm,” and, the rice water weevil (RWW, *Lissorhopterus oryzae*). Both of these pests have the potential to substantially reduce plant stand and subsequent yield in any given year. Prior to the development of new insecticide seed treatments (ISTs) in 2007, there were few options for control of these key pests. Draining the field after infestation is still one of the most effective options, but the high cost of pumping in recent years has deterred growers from this practice (Thompson et al., 1994). Applying foliar insecticide has also been used as a means to control adult RWW and GC; however, difficulty in timing the application properly results in ~ 50% effectiveness (Fig. 1).

Cruiser® 5FS (Syngenta Crop Protection) and Dermacor® X-100 (DuPont) were granted full labels for use during the spring of 2010. In the U.S., prior to 2010, an extensive testing program was conducted through Experimental Use Permits (EUP). In 2008, Arkansas received a Section 18 with Louisiana and Mississippi for Dermacor and we were able to observe the product in large block trials to verify small block test results (Wilf et al., 2009a, 2009b, 2009c). In 2009, Dermacor received a full label and Arkansas was the only state granted a Section 18 for Cruiser. We were able to compare Cruiser to Dermacor and untreated checks in several locations across the rice growing area of the state in large and small plot trials (Wilf et al., 2010a, 2010b; Fortner et al., 2011a, 2011b, 2011c, 2011d, 2011e). In 2011, a third seed treatment, NipsIt Inside, became available on limited acreage; an EUP was granted on 40,000 acres of which 20,000 was allotted in Arkansas. The opportunity to evaluate this product in small plots as well as on grower fields across the state provided a good opportunity to evaluate the product on large plot trials in the state (Lorenz et al., 2012; Plummer et al., 2012; Taillon et al., 2012). NipsIt Inside (Valent) received a full label for use in the fall of 2012 (Everett et al., 2013; Taillon et al., 2013a, 2013b). In 2011, the Cruiser formulation was changed to Cruiser Maxx Rice which includes a premix of Cruiser and fungicides.

PROCEDURES

Experiments and demonstrations were conducted from 2007 to 2013 on numerous grower fields across the state, the Pine Tree Research Station, near Colt, Ark., and the Rice Research Extension Center, near Stuttgart, Ark. These trials consisted of small plot replicated experiments and large plot demonstration trials and the comments on these seed treatments herein, are based on these observations. In these trials we have used seeding rates ranging from 20 lb/acre to 120 lb/acre. We have observed these seed treatments on conventional, Clearfield, and hybrid types of rice. The selection of locations was based on fields with a history of problems with either grape colaspis or rice water weevil. However, we did not experience insect problems in every field.

Core samples (4-inch diameter) were collected at 3 to 5 weeks post flood and transported to the laboratory. Samples were washed through a 0.25-inch screen into a 40-mesh sieve to collect RWW and GC larvae. The sieves were placed in a 5% salt water solution and the numbers of larvae that floated to the surface were counted. At the end of the season, plots were harvested and yields were measured and converted to bushels per acre. Data is processed using the latest version of Agriculture Research Manager (Gylling Data Management, Inc., Brookings, S.D.), analysis of variance, and Duncan's New Multiple Range Test (*P* = 0.10).

RESULTS AND DISCUSSION

Throughout the testing of these seed treatments, we have seen a general trend to improve stand count and vigor in many fields with the use of seed treatments (Fig. 1). Seed treatments have increased stand counts in many trials as much as 10% to 20% above the untreated check. We have also documented increased plant height in some fields (Fig. 2). The amount of vigor seen may be dependent on many factors including pest pressure, environmental conditions, and seed quality. Many times we have observed under stressful conditions the seed treatment helped to moderate or buffer stress. The insecticide seed treatments have continued to provide good control of RWW in Arkansas. Percent control over the 3 years averaged 74% control depending on initial larval densities. Seed treatments provide good control when moderate populations of RWW are present on roots (Figs. 3 and 4). When higher populations occur (>20 larvae/core), NipsIt Inside and Cruiser provide adequate control while Dermacor provides a slightly higher level of control. Each of the seed treatments provided benefits in terms of yield (Fig. 5). Over the 5 year period, Dermacor provided a 7 bu/acre yield increase, Cruiser provided a 6 bu/acre yield increase, and NipsIt Inside provided a 6 bu/acre increase. Based on the yield results shown in the figures below, Dermacor, Cruiser, and NipsIt provided a 75%, 73%, and 81% probability of a net return, respectively.

Based on these results, insecticidal seed treatments are recommended for RWW control in Arkansas. Cruiser and NipsIt Inside are recommended for GC control and Dermacor for suppression of GC.

SIGNIFICANCE OF FINDINGS

Since our work with insecticide seed treatments began in 2007, we have seen consistent value with these products. Insecticide seed treatments are easily applied and give producers a more reliable option against RWW and GC compared to foliar applications. This body of work has helped develop our recommendations to the rice producers of Arkansas.

ACKNOWLEDGMENTS

We would like to express our appreciation to Arkansas rice producers, Arkansas Rice Research and Promotion Board, Dupont, Syngenta, and Valent for their support. We would also like to acknowledge the many county agents that helped with these trials.

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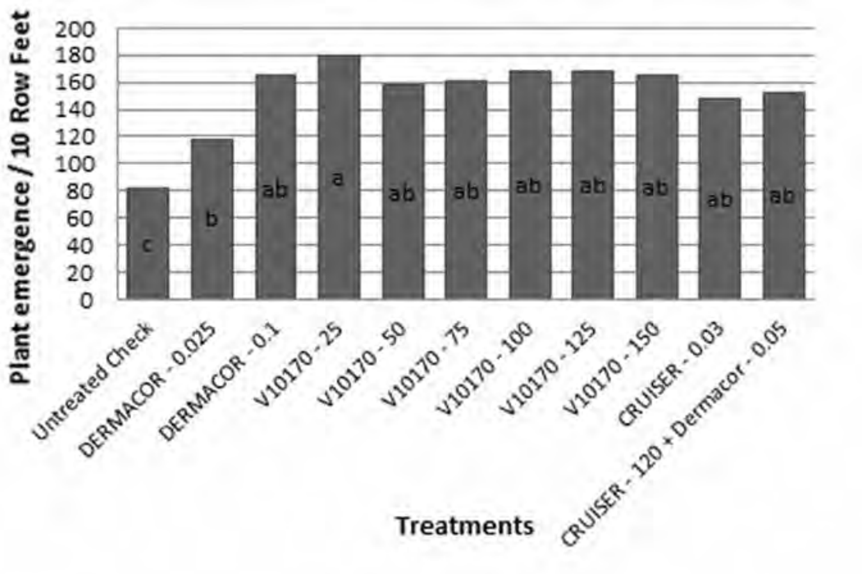

Fig. 1. Stand counts for selected insecticide seed treatments, number of plants/10 row-ft. Prairie County, Price Farm, 2008.

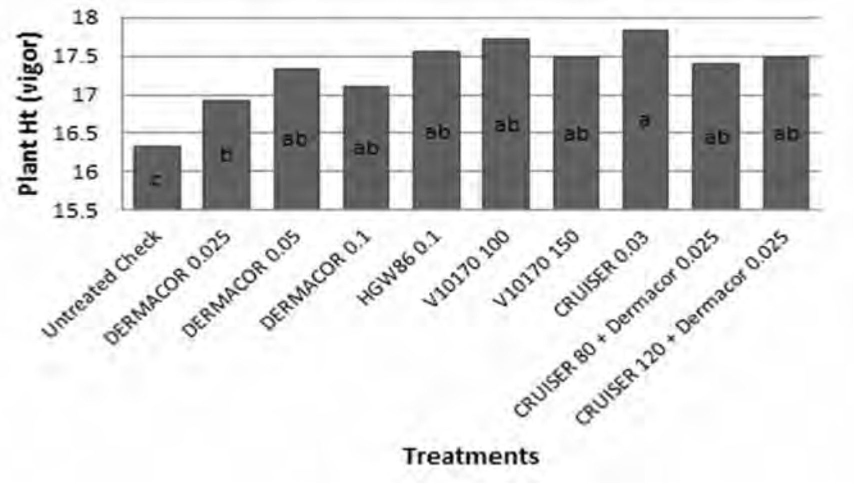

Fig. 2. Vigor rating for selected seed treatments, average plant height of 5 plants/10 row-ft. Prairie County, Price Farm, 2008.

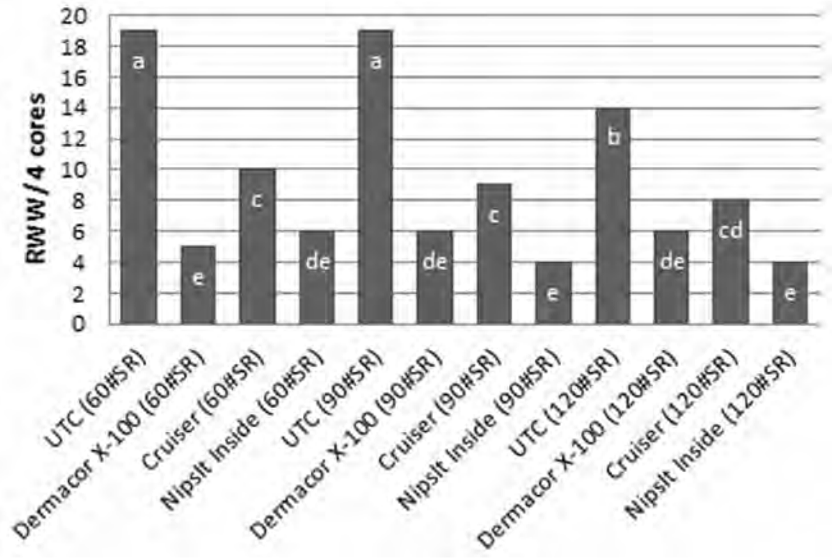

Fig. 3. Insect counts for selected insecticide seed treatments, rice water weevils/4 cores. Conventional seeding rate summary across 4 locations, 2010.

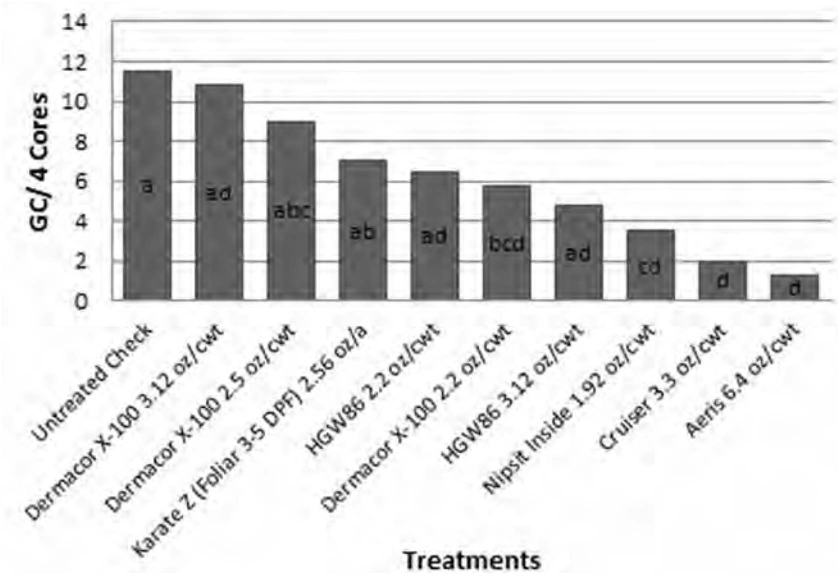

Fig. 4. Insect counts for selected insecticide seed treatments, grape colaspis/4 cores. St. Francis County, DuPont (Pine Tree, Ark.) 2009.

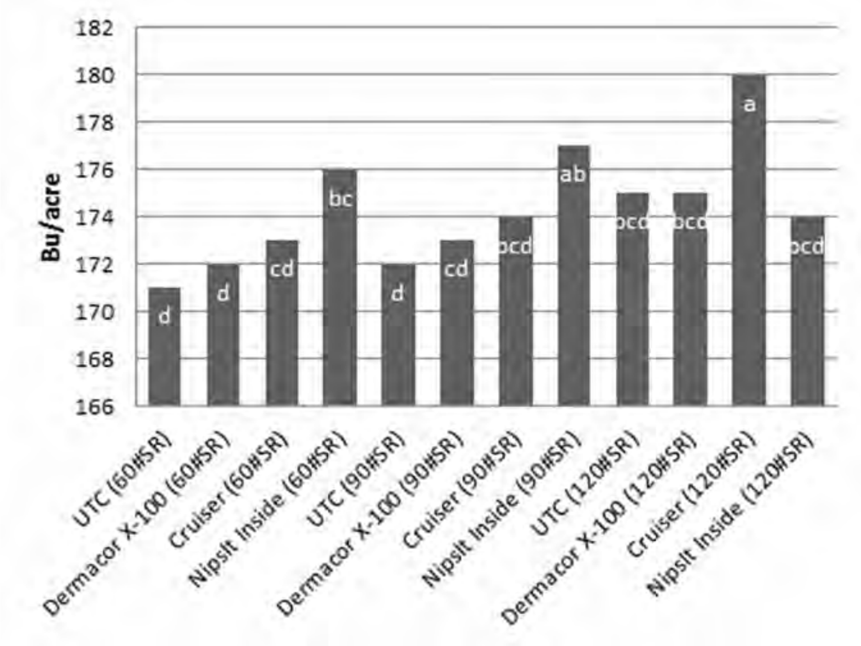

Fig. 5. Harvest data for selected insecticide seed treatments, bu/acre. Conventional seeding rate summary across locations, 2010.

Comparison of Growth Characteristics Between Halosulfuron-Methyl-Resistant and Susceptible Yellow Nutsedge Populations

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ABSTRACT

A yellow nutsedge (*Cyperus esculentus* L.) population collected from eastern Arkansas was confirmed to show high levels of resistance to halosulfuron-methyl (Permit®), an acetolactate synthase (ALS)-inhibiting herbicide used in rice production. In the present investigation, growth characteristics of the ALS-inhibitor-resistant (Res) yellow nutsedge population was compared with three susceptible (Sus 1 to 3) populations originating from different locations within the same geographical region. Growth comparisons were made using two greenhouse experiments, conducted using a completely randomized design with four replications and two runs. The first experiment allowed the comparison of growth habit under the absence of competition for space. For each treatment, a single seedling was transplanted to the center of a nursery flat (6.5 cm × 40 cm × 54 cm) and allowed to grow for 50 days, after which they were harvested to measure number of shoots produced, shoot weight, and root weight from each sample. The second experiment was conducted to compare growth and reproduction under competition for space (using 18-cm deep × 17-cm radius pots) for an extended period of 150 days. From each sample, shoot weight, root weight, tuber numbers, and tuber weight were determined. The Res population showed a radically different growth habit, with new shoots emerging away from the mother plant. Within 15 days after transplanting, Res plants moved to as far as 27 cm, at which point the Sus populations did not spread beyond 5 cm from the mother plants. The Res population produced significantly less tubers, which were typically smaller than those of Sus populations. The Res population flowered under greenhouse conditions (16 hour photoperiod and 20/30 °C day/night temperature), whereas none of the Sus populations transitioned to flowering phase under the same environment.

INTRODUCTION

Yellow nutsedge is becoming an increasingly problematic weed in rice-soybean production systems of the Mississippi Delta region. Yellow nutsedge is a perennial weed with predominant reproduction by underground tubers, which are primarily responsible for overwinter survival of this species. A report by Doty (1973) suggested that tubers can survive in the soil for up to 3.5 years, but the majority of them do not survive past two winters. Although tuber production is critical for population establishment and spread, viable seed production and germination has also been observed to some extent (Larssen, 1960). Bell and Larssen (1960) reported yellow nutsedge seed germination ranging from 28% to 89% across different environments. Despite the reports that yellow nutsedge can produce viable seeds with good germination potential, there is limited evidence that yellow nutsedge seeds can produce plants under natural conditions (Mulligan and Junkins, 1976).

It is generally expected that the majority of yellow nutsedge populations are genetically similar. However, some researchers have documented the existence of considerable genetic diversity in yellow nutsedge populations (e.g., Okoli et al., 1997), which may favor adaptation under diverse environmental conditions. Evidence suggests that yellow nutsedge has been spreading outside of its native range, adapting to new environments where it was not previously present (Mulligan and Junkins, 1976). The existence of genetic diversity may also favor the evolution of herbicide resistance in weeds.

Recently, a yellow nutsedge population was confirmed to exhibit resistance to halosulfuron-methyl (the active ingredient of the herbicide Permit®). To our knowledge, this is the first report of herbicide resistance in yellow nutsedge. Dose-response assays confirmed that the acetolactate synthase (ALS)-inhibitor-resistant (Res) population exhibited very high levels (>32 fold) of resistance to this herbicide (unpublished results). Studies have shown that (reviewed in Vila-Aiub et al., 2009) the long-term dynamics of a herbicide-resistant population is greatly influenced by the changes to key life histories as governed by resistance. However, little is known as to whether the growth and reproductive characteristics of the Res and susceptible (Sus) populations are different. The overall objective of this study was to understand the growth characteristics of the Res yellow nutsedge population collected from eastern Arkansas and compare it with Sus populations.

PROCEDURES

Greenhouse experiments were conducted at the University of Arkansas System Division of Agriculture, Agricultural Research and Extension Center, Fayetteville. Preliminary observations involving the Res population suggested that this population is characterized by a substantially different shoot emergence pattern, in which new shoots emerge away from the mother plants. To account for the differences in distance of movement and also to test for differences in growth and reproduction between the Res and Sus populations, two separate experiments (experiment I, II) were carried out in the greenhouse. Both experiments were arranged in a completely randomized design with four replications and two experimental runs.

In experiment I, the growth patterns of the various yellow nutsedge populations were studied using large nursery flats (6.5 cm × 40 cm × 54 cm). This set-up allowed for the comparison of growth patterns when there was no competition for space. Seedlings pertaining to each treatment were transplanted to the center of each tray at the 2- to 3-lf stage. Plants were watered and fertilized as necessary. Number of new shoots produced and distance of movement from the mother plant were recorded every 15 days. After each count, newly emerged shoots were marked using colored toothpicks. The experiment I was terminated at 50 days after transplanting (DAT), at which point the Res plants were widely distributed within the trays and occupied the majority of the space. The plants were harvested and measurements were made on total number of shoots produced and shoot dry weight accumulation from each sample. Potting media was removed using running water and root dry weights were documented subsequently.

In experiment II, growth and reproductive potentials were compared between the yellow nutsedge populations using plastic pots (18 cm deep × 17 cm radius) in a greenhouse at 30/20 °C and 16 hour photoperiod. Plants were allowed to grow for 150 days within this limited space, but were watered and fertilized as needed. Number of days required for the initiation of flowering was recorded. At the end of the trial (i.e., 150 DAT), plants from each pot were harvested and from each sample, shoot weight, root weight, tuber numbers, and tuber weight were determined.

Data were analyzed using the Statistical Analysis Software, SAS V. 9.3 (SAS Institute, Cary, N.C.). Significance of treatment effects were investigated using a Generalized Linear Model using the GLM procedure of SAS. Prior to each ANOVA, normality of the dataset was tested using the UNIVARIATE procedure of SAS. Mean separations were carried out using the Fisher's Protected Least Significant Difference method ($P = 0.05$).

RESULTS AND DISCUSSION

Results confirmed that the Res population exhibits a drastically different growth habit compared to the Sus populations (Fig. 1). New shoots from the Res plants emerged away from the mother plants, whereas the shoots of the Sus plants were produced in a tuft. The Res plants reached the farthest distance of 27 cm from the mother plant in the trays within 15 DAT, at which point the Sus plants had not spread beyond 5 cm. The ability of the Res plants to produce new shoots away from the mother plant suggests that patch expansion can be rapid in this population. In doing so, the Res population also appears to minimize self-shading and spread the root mass widely in the soil column (Fig. 2). Conversely, the root mass of the Sus plants were confined to a zone around the clump. Moreover, dry root mass of the Res population was generally on par with and in one case superior to the Sus populations (Table 1). The ability to spread out the root system with considerably high root mass might be beneficial to the Res population in sourcing soil moisture and nutrients effectively. Results of experiment I also showed that the Res population was comparable to or superior to the Sus populations for shoot density and shoot weight (Table 1). In fact, individual shoots of the Res population generally appeared to be thinner and weaker compared to the Sus populations, particularly during early stages of establishment. However, the Res plants seemingly compensated by avoiding competition among the shoots especially for light, leading to comparable or superior final shoot dry weights.

In experiment II, there were no differences between the Res and Sus populations for shoot or root mass (Table 2), possibly because they all reached carrying capacities for shoot and root production in the pots prior to termination of the experiment. However, there were significant differences for tuber production. The Res plants produced significantly fewer tubers with lesser tuber weights compared to the Sus plants. It is not clear whether reduction in tuber production is a detriment to the spread of the Res population, but it appears that the ability to spread out can compensate for the reduction in tuber production. We also speculate that the Res population may have differential seed viability and emergence characteristics compared to the Sus populations, but this is yet to be tested. All the Res plants flowered under greenhouse conditions, but none of the Sus plants transitioned to flowering phase.

Research is underway to characterize the photoperiodic requirements for flowering and to test for differences in seed production, viability, and seedling emergence among the Res and Sus populations. Growth and tuber characteristics of the Res population lead to a suspicion that this population may be a hybrid between purple and yellow nutsedge. Research is also being carried out to verify the genetic background of the Res population.

SIGNIFICANCE OF FINDINGS

The observation that the Res population shows growth characteristics different from Sus populations, with an ability to rapidly spread and colonize a production field suggests that early-season weed control measures are critical to prevent the spread of this population. Results also suggest that tillage can be a useful tool, but care should be taken to prevent the movement of tubers through tillage equipment.

ACKNOWLEDGMENTS

Funding for this research was provided in part by the Arkansas Rice Research and Promotion Board.

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Table 1. Growth comparison between the resistant (Res) and susceptible (Sus) populations under the absence of competition for space†.

		Weight	
Pop	Shoot density	Shoot	Root
	(no./plant)	-------------- (g/plant)	--------------
Sus-1	98.0 a	50.9 b	35.3 ab
	(6.6)	(6.7)	(5.8)
Sus-2	56.9 b	44.9 b	23.9 b
	(4)	(5.1)	(1.9)
Sus-3	72.1 b	54.7 ab	38.2 ab
	(8.1)	(6.7)	(5.0)
Res	111.3 a	69.8 a	48.8 a
	(10.6)	(6.4)	(7.7)

† Observations were made at 50 d after transplanting. Values in parenthesis indicate standard errors of mean. Within each column, mean values followed by different letters indicate significant differences (*P* = 0.05).

Table 2, Growth and reproductive comparison between the resistant (Res) and susceptible (Sus) populations under competition for space†.

			Weight	
Pop	Tuber density	Tuber	Shoot	Root
	(no./plant)	-------------------	(g/plant)	------------------------------
Sus-1	1706 a	249.0 b	386.0 a	761.4 a
	(176)	(11.5)	(43.8)	(71.3)
Sus-2	1248 b	405.0 a	269.2 a	692.0 a
	(49)	(52.7)	(37.1)	(73.0)
Sus-3	1231 b	391.2 a	343.7 a	669.2 a
	(125)	(23.8)	(19.3)	(76.4)
Res	825 c	153.6 c	353.3 a	655.0 a
	(48)	(16.4)	(34.0)	(57.1)

† Observations were made at 150 d after transplanting. Values in parenthesis indicate standard errors of mean. Within each column, mean values followed by different letters indicate significant differences (*P* = 0.05).

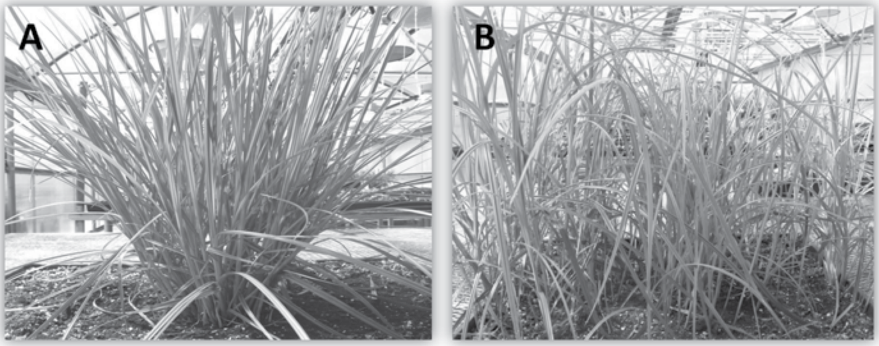

Fig. 1. Comparison of growth habits between susceptible (A) and resistant (B) yellow nutsedge populations.

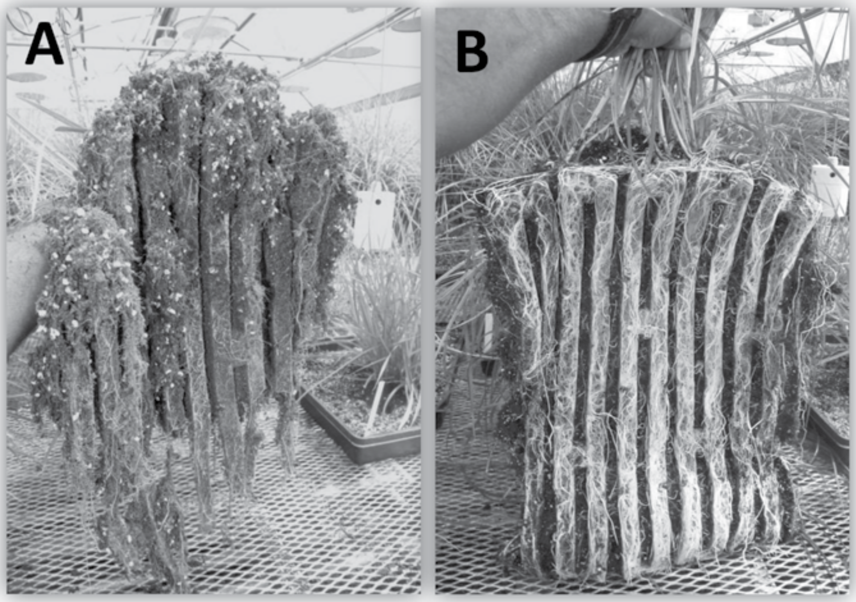

Fig. 2. Comparison of root distribution between susceptible (A) and resistant (B) yellow nutsedge populations at 50 days after transplanting under the absence of competition for space.

Influence of Rate and Application Timing on Rice Tolerance to Pyroxasulfone

M.T. Bararpour, J.K. Norsworthy, D.B. Johnson, R.C. Scott, and T.L. Barber

ABSTRACT

Two separate field studies were conducted at the University of Arkansas System Division of Agriculture Northeast Research and Extension Center (NEREC; Keiser, Ark.) and at the Rice Research and Extension Center (RREC; near Stuttgart, Ark.) in 2011 to evaluate the effect of post-emergence (POST) applications of pyroxasulfone (Zidua) at various rates on rice tolerance. The experiment was designed as a three (application timings) by four factorial (pyroxasulfone rates) in a randomized complete block design. Pyroxasulfone was applied POST at 0.045, 0.067, and 0.08 lb ai/acre (sub-factor) at spiking, 2-lf, and 4-lf stage of rice. On a clay soil at Keiser, 5 weeks after emergence the effect of timing by rate was significant for rice injury. Rice injury was 8% to 29%, 0% to 3%, and 3% to 21% when pyroxasulfone was applied at spiking, 2-lf, and 4-lf stage of rice, respectively. Rice yield was not affected by application timings or rates. At Stuttgart, rice injury was 75% to 81%, 69% to 76%, and 6% to 31% following pyroxasulfone applications at spiking, 2-lf rice, and 4-lf rice, respectively. Rice yield was reduced 53% to 89%, 47% to 79%, and 16% to 32% from pyroxasulfone applications at spiking, 2-lf, and 4-lf rice, respectively. In 2013, at Stuttgart, an experiment was conducted to determine the risk of carryover of pyroxasulfone to rice based on various half-lives of the herbicide. The experiment was designed as a randomized complete block with eight treatments and four replications. The treatments were 0.0021 (1/64×), 0.0042 (1/32×), 0.0084 (1/16×), 0.0166 (1/8×), 0.0332 (1/4×), 0.0664 (1/2×), and 0.133 lb ai/acre (1× rate for soybean) applied pre-emergence (PRE) along with a nontreated control. At 5 weeks after emergence, rice injury was 15%, 30%, 56%, and 88% from the applications of pyroxasulfone PRE at 0.0166 to 0.133 lb ai/acre, which would correspond to three or fewer half-lives. Pyroxasulfone applied PRE at 0.0664 and 0.133lb ai/acre reduced yield 29% and 79%, respectively.

INTRODUCTION

Weed management programs are an essential component of rice production. Rice, wheat, and corn are the three leading food crops in the world. Arkansas has been the nation's leading rice-producing state since 1973. In 2011, barnyardgrass (*Echinochloa crus-galli*) was listed by crop consultants as the most problematic weed of rice in Arkansas (Norsworthy et al., 2012). Season-long interference of barnyardgrass at a density of even one plant/11 ft^2 can reduce rice yield up to 230 lb/acre (Stauber et al., 1991). In Arkansas, lack of rotation of rice with other crops along with frequent use of propanil, quinclorac, and clomazone have led to the evolution of barnyardgrass biotypes resistant to these herbcides. Therefore, finding and testing a new herbicide to use in rice fields is essential. Pyroxasulfone was recently labeled for use in Arkansas for corn, soybean, and wheat. It has annual grass activity similar to metolachlor (Dual) and acetochlor (Harness) but also provides good control of several annual broadleaves. Pyroxasulfone is sold under the trade name Zidua 85WG by BASF, but is also being marketed by FMC and Valent as a premix with other herbicide active ingredients. Pyroxasulfone has the same mode of action as the acetanilides (G15 = inhibition of cell division) (Dual, Outlook, Harness/Surpass) but use rates are 3 to 8 times lower, and residual control on certain weeds such as Palmer amaranth (*Amaranthus palmeri*) and ryegrass (*Lolium*) appears to be longer than with other herbicides having the same mode of action. It has very low water solubility and requires ample rainfall for activation. Currently, pyroxasulfone has a 10- to 24-month rotation restriction to rice, depending upon the rate used in the previous crop (Anonymous, 2014).

PROCEDURES

Field studies were conducted at the University of Arkansas System Division of Agriculture Northeast Research and Extension Center, Keiser, Ark. (NEREC, Sharkey clay soil) and the Rice Research and Extension Center near Stuttgart, Ark. (RREC, Dewitt silt loam soil) in 2011 to evaluate the influence of post-emergence (POST) applications of pyroxasulfone at various rates on rice tolerance. The experiment was designed as a three (application timings) by four (pyroxasulfone rates) factorial in a randomized complete block design. Pyroxasulfone was applied at 0.045, 0.067, and 0.08 lb ai/acre (sub-factor) at spiking, 2-lf, and 4-lf stage of rice (main factor). Rice (Clearfield 142) was seeded with a 9-row drill on 7-inch spacing at a rate 24 seed/ft of row in 6-ft wide by 20-ft long plots. The experimental site was sprayed with clomazone (Command) at 0.3 lb ai/acre plus quinclorac (Facet) at 0.375 lb ai/acre PRE followed by imazethapyr (Newpath) at 0.063 lb ai/acre preflood for weed control.

In 2013, a field study was conducted at the RREC to evaluate rice tolerance to simulated half-lives of pyroxasulfone applied pre-emergence (PRE). The experiment was designed as a randomized complete block design with eight treatments and four replications. Pyroxasulfone was applied PRE at 0.0021 (1/64×), 0.0042 (1/32×), 0.0084 (1/16×), 0.0166 (1/8×), 0.0332 (1/4×), 0.0664 (1/2×), and 0.133 lb ai/acre (1× rate for soybean). The experimental site was sprayed with clomazone at 0.3 lb ai/acre PRE followed by imazethapyr at 0.063 lb ai/acre + quinclorac at 0.25 lb ai/acre (pre-flood) followed by cyhalofop (Clincher) at 0.25 lb ai/acre for weed control (to keep the test area clean).

For both trials, all herbicide applications were made with a CO_2-pressurized backpack sprayer calibrated to deliver 15 gal/acre. Visible estimates of rice injury were recorded bi-weekly throughout the growing season to evaluate rice tolerance to pyroxasulfone. Data were subjected to analysis of variance, and means were separated by Fisher's Protected Least Significant Difference (LSD) test at the 5% level of significance. Results differed by location in 2011; hence, locations are presented separately.

RESULTS AND DISCUSSION

In 2011, at both locations (NEREC and RREC), the effect of timing by rate was significant for rice injury at 5 weeks after emergence (WAE). At the NEREC, rice injury was 8% to 29%, 0% to 3%, and 3% to 21% for the various pyroxasulfone rates applied at spiking, 2-lf, and 4-lf stage of rice, respectively (Fig. 1). Greater rice injury occurred at the RREC than at the NEREC. Rice injury caused by pyroxasulfone was 75% to 81% from spiking treatments, 69% to 76% from 2-lf treatments, and 6% to 31% from 4-lf treatments (Fig. 2). At the NEREC, rice yield was not affected by application timings or pyroxasulfone rates. At the RREC, the effect of timing by rate interaction was significant. In general, rice yield was less affected by pyroxasulfone applications at the 4-lf stage of rice than at spiking or 2-lf rice (Fig. 3). Rice yield was reduced 53% to 72%, 47% to 79%, and 16% to 32% by pyroxasulfone applied to spiking, 2-lf, and 4-lf rice, respectively.

In 2013, on a silt loam soil at the RREC, one WAE, there was significant rice injury when pyroxasulfone was applied PRE at rates above 0.0084 lb ai/acre (1/16×) (Table 1). Similarly, rates above 0.0084 lb ai/acre reduced rice stands by 25% to 99% relative to the nontreated check (Table 2). The initial injury observed at rates above 0.0084 lb ai/acre generally declined over the course of the growing season. By 5 WAE, rice injury had decreased to 15%, 30%, 56%, and 88% from applications of pyroxasulfone at 0.0166, 0.0332, 0.0664, and 0.133 lb ai/acre, respectively (Table 1). Rice yield was not affected by the application of pyroxasulfone PRE at 0.0021 up to 0.0332 lb ai/acre compared to the nontreated check (Table 2). However, pyroxasulfone at 0.0664 and 0.133 lb ai/acre reduced rice yield 29% and 79%, respectively. Even though pyroxasulfone at 0.0166 and 0.0332 lb ai/acre reduce the rice stand, grain yields were not reduced probably because the lower population compensated by increasing tillers and panicle number per plant.

SIGNIFICANCE OF FINDINGS

In general, pyroxasulfone is injurious to rice, whether applied PRE or POST and care should be taken to insure that pyroxasulfone does not carryover to rice. At the current Zidua use rate of 2.5 oz/acre (0.133 lb ai/acre), it appears that four half-lives would need to be completed before rice can safely be planted back into fields treated the previous year with pyroxasulfone. Based on the 2011 results, it appears that soil type is likely a major contributor as to likelihood of seeing injury from pyroxasulfone.

ACKNOWLEDGMENTS

We would like to thank the Arkansas Rice Research and Promotion Board for funding this research.

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Table 1. Rice injury from pyroxasulfone one, three, and five weeks after emergence (WAE) at the Rice Research and Extension Center, near Stuttgart, 2013[†].

	Injury		
Pyroxasulfone rate	1 WAE	3 WAE	5 WAE
(lb ai/acre)	(%)		
0.0021	0 d	0 d	1 e
0.0042	0 d	0 d	3 e
0.0084	7 d	1 d	5 de
0.0166	31 c	15 c	15 d
0.0332	60 b	35 b	30 c
0.0664	92 a	95 a	56 b
0.133	99 a	99 a	88 a

[†] Means followed by the same letter are not significantly different according to Fisher's Protected Least Significant Difference test at $P = 0.05$.

Table 2. Effect of pyroxasulfone on rice stand and yield at the Rice Research and Extension Center, near Stuttgart, 2013.[†]

Pyroxasulfone rate	Rice stand count	Yield	Yield reduction
(lb ai/acre)	(3 ft of row)	(bu/acre)	(% of nontreated)
0.0	68 a	126 a	---
0.0021	65 a	129 a	0
0.0042	64 a	123 a	2
0.0084	64 a	128 a	0
0.0166	48 b	132 a	0
0.0332	33 c	124 a	2
0.0664	7 d	90 b	29
0.133	1 d	27 c	79

[†] Means followed by the same letter are not significantly different according to Fisher's Protected Least Significant Difference test at $P = 0.05$.

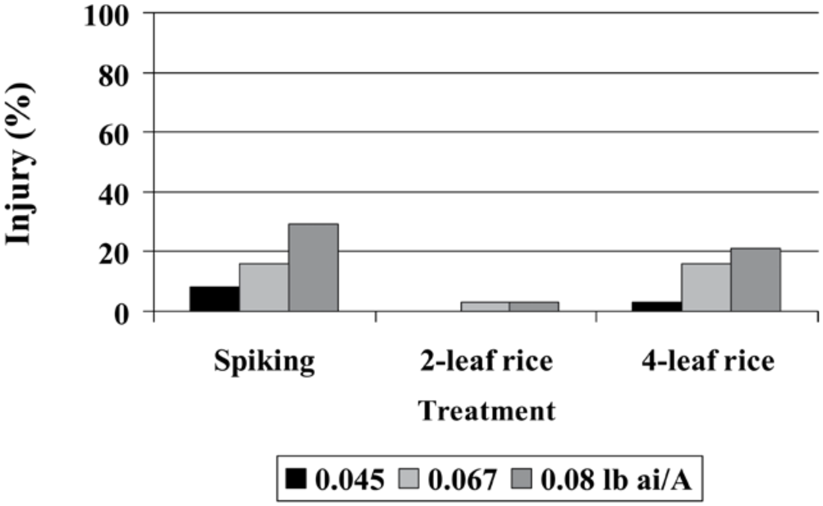

Fig. 1. Effect of rate and application timing on rice tolerance to pyroxasulfone at the Northeast Research and Extension Center, Keiser, 2011 at 5 weeks after emergence (Least Significant Difference = 5).

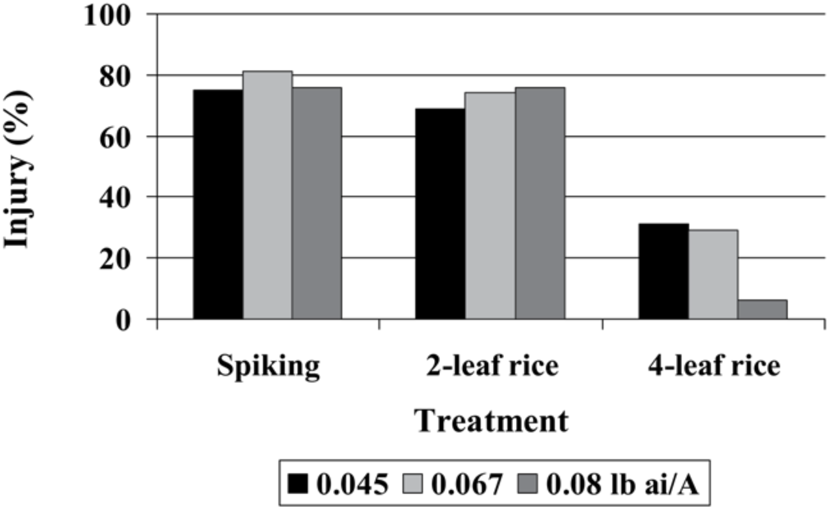

Fig. 2. Effect of rate and application timing on rice tolerance to pyroxasulfone at the Rice Research and Extension Center near Stuttgart, 2011 at 5 weeks after emergence (Least Significant Difference = 10).

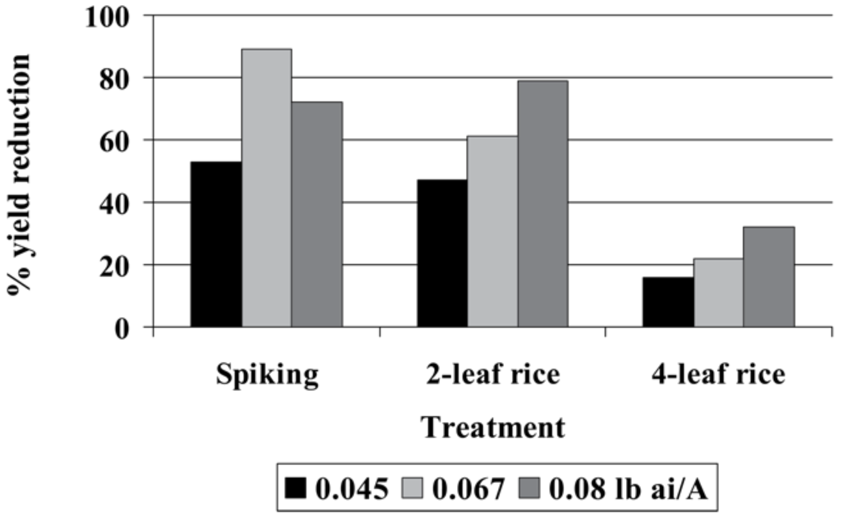

Fig. 3. Effect of rate and application timing on rice yield reduction from pyroxasulfone at the Rice Research and Extension Center near Stuttgart, 2011 (Least Significant Difference = 20).

PEST MANAGEMENT: WEEDS

Early-Season Palmer Amaranth Interference in Rice, Potential Yield Losses, and Control Options

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ABSTRACT

Herbicide-resistant Palmer amaranth (*Amaranthus palmeri*) is one of the most problematic weeds facing producers in the southern United States today. In a survey conducted by Norsworthy et al. (2013) in 2011, crop consultants listed Palmer amaranth as one of the five most important weeds in rice production. Improved control options for Palmer amaranth and the effect of Palmer amaranth on early-season interference are two of the most important areas of research and educational needs in rice as identified by consultants. Three field studies were conducted in 2013 at University of Arkansas System Division of Agriculture Pine Tree Research Station near Colt, Ark., to evaluate herbicide programs for Palmer amaranth control and potential yield loss associated with early-season Palmer amaranth interference in rice. The first trial was designed to evaluate the efficacy of various pre-emergence (PRE) herbicide programs for controlling Palmer amaranth. Clomazone, pendimethalin, imazosulfuron, thiobencarb, and quinclorac were applied PRE or delayed PRE (DPRE) and evaluated for control of Palmer amaranth. Clomazone (0.3 lb ai/acre) plus quinclorac (0.5 lb ai/acre) applied PRE provided the best control of Palmer amaranth with greater than 92% control 6 weeks after treatment (WAT) compared to 80% control with clomazone alone. In the second trial, application timing was evaluated for effectiveness of early post-emergence (EPOST) Palmer amaranth control options. Five herbicide programs were applied at two different timings, EPOST and preflood (PREFLD). Propanil (4 lb ai/acre) plus acifluorfen (0.25 lb ai/acre) provided the highest level of control for Palmer amaranth with greater than 94% control 2 WAT EPOST, which was significantly better than propanil alone. Rice yields were significantly higher for PREFLD applications than for EPOST treatments, with the exception of propanil (4 lb/acre) applied with carfentrazone (0.016 lb ai/acre) and quinclorac (0.5 lb/acre). Higher yields with PREFLD applications can mostly be attributed to better control of hemp sesbania (*Sesbania herbacea*) and barnyardgrass (*Echinochloa crus-galli*) post-flood. For the third study, Palmer amaranth was spread at 0, 12, 60, 300, and 1500 seeds/m^2 at planting in both hybrid rice, seeded at 6 seed/ft of row, and conventional rice, seeded at 24 seed/ft of row to determine if yield losses could result from early-season competition. On average, yield for hybrid rice was higher than conventional rice by 27 bu/acre, although weed competition reduced yields for both rice types similarly. Palmer amaranth stand counts were determined in each plot prior to flooding and as Palmer amaranth density increased by 10 plants/m^2, yield decreased by an estimated 1.3 bu/acre. The results from these three experiments shows that there is potential for yield loss due to early-season Palmer amaranth interference in rice, and that season-long herbicide programs are essential to maximize yields in rice.

INTRODUCTION

Weed management is essential for successful production of rice. Arkansas ranks first among U.S. rice-producing states comprising more than 1.2 million acres of cropland grown every year. Herbicide-resistant Palmer amaranth has become one of the most problematic weeds in agronomic crops in the southern United States (Jha and Norsworthy, 2012). Early-season Palmer amaranth interference is becoming a major concern for rice producers in Arkansas. A survey of rice consultants in 2011 ranked Palmer amaranth as one of the top five most important weed species in rice, and one of the most important needs for research along with barnyardgrass (Norsworthy et al., 2013). Herbicide-resistant Palmer amaranth is prevalent in soybean fields across Arkansas, the crop most commonly rotated with rice. In addition to the prevalence of Palmer amaranth in rice fields, it is difficult to control on rice levees because of 2,4-D restrictions in the state (Norsworthy et al., 2013).

Direct dry-seeding is the most commonly used method for growing rice in Arkansas, and subsequently a 2- to 6-inch permanent flood is established 4 to 5 weeks after planting (Norsworthy et al., 2008). Continuous flooding reduces emergence and growth of most semi-terrestrial broadleaf and grass weeds in rice; however, controlling weeds such as Palmer amaranth between planting and flood is critical for maximizing yields in dry-seeded rice (Riar and Norsworthy, 2011).

Numerous residual herbicides are available for pre-emergence (PRE) and delayed pre-emergence (DPRE) weed control including pendimethalin, clomazone, quinclorac, and thiobencarb (Riar and Norsworthy, 2011). Adoption of imidazolinone-resistant rice has increased tremendously as well as the increased use of imazethapyr and other acetolactate synthase (ALS)-inhibiting herbicides (Riar et al., 2013). In most cases, ALS inhibiting herbicides provide poor control of Palmer amaranth due to widespread resistance to the mechanism of action (Norsworthy et al., 2008). The objectives of this research were to 1) evaluate Palmer amaranth control with various pre-emergence-applied herbicide programs in rice, 2) determine efficacy of different post-emergence options for the control of Palmer amaranth, and 3) determine the potential yield loss associated with early-season interference in Palmer amaranth.

PROCEDURES

Three field experiments were set up at the University of Arkansas System Division of Agriculture Pine Tree Research Station near Colt, Ark., in 2013 on a Calloway silt loam soil. To determine the effects of various PRE-applied herbicide programs on Palmer amaranth control in rice, a study was conducted as a randomized complete block design with each treatment replicated four times. Rice cultivar CL142 was drilled seeded at a rate of 24 seed/ft of row in plots 6-ft wide by 25-ft long. Treatments evaluated included 1) clomazone (0.3 lb ai/acre) as Command applied PRE, 2) clomazone (0.3 lb/acre) PRE followed by (fb) pendimethalin (1.0 lb ai/acre) as Prowl H_2O applied DPRE, 3) clomazone (0.3 lb/acre) PRE tankmixed with imazosulfuron (0.3 lb ai/acre) as League applied PRE, 4) clomazone (0.3 lb ai/acre) PRE fb thiobencarb (4.0 lb ai/acre) as Bolero applied DPRE, 5) pendimethalin (1.0 lb/acre) DPRE tankmixed with thiobencarb (4.0 lb/acre) DPRE, 6) clomazone (0.3 lb/acre) PRE tankmixed with quinclorac (0.5 lb ai/acre) as Facet applied PRE, and a nontreated check. Each treatment received propanil (4.0 lb ai/acre) early post-emergence (EPOST) and preflood (PREFLD) to control late-season weeds such as hemp sesbania and barnyardgrass. Treatments were visually rated for Palmer amaranth, barnyardgrass, broadleaf signalgrass, and hemp sesbania at 2, 4, and 6 WAT on a scale of 0 to 100 where 0 is no control and 100 is complete control. Rice was harvested using a small-plot combine, grain moisture was determined, and yields were converted to bu/acre. Rating and yield data were subjected to analysis of variance, and means were separated using the Fisher's Protected Least Significant Difference test at the 0.05 level.

A second study was conducted at the same site to evaluate the influence of application timing on Palmer amaranth control. Clearfield 142 was drill seeded at 24 seeds/ft of row in 6-ft wide by 25-ft long plots. The experiment was set up in a randomized complete block design with a two by five factorial arrangement of treatments with four replications. The first factor consisted of two application timings EPOST and PREFLD. The second factor consisted of five herbicide applications including 1) propanil (4.0 lb/acre), 2) propanil (4.0 lb/acre) plus triclopyr (0.25 lb ae/acre) as Grandstand, 3) propanil (4.0 lb/acre) plus acifluorfen (0.25 lb ai/acre) as Ultra Blazer, 4) propanil (4.0 lb/acre) plus carfentrazone (0.016 lb ai/acre) as Aim, and 5) propanil (4.0 lb/acre) plus carfentrazone (0.016 lb/acre) plus quinclorac (0.5 lb/acre). A nontreated control was included for comparison. Treatments were visually rated for control of Palmer amaranth, barnyardgrass, broadleaf signalgrass, and hemp sesbania at 1, 2, and 4 weeks after the EPOST treatment. Subsequent weed control ratings were recorded post-flood. Rice was harvested using a small-plot combine. Ratings and yield data were subjected to analysis of variance, and means were separated using the Fisher's protected LSD test at the 0.05 level.

A third study conducted at the same site aimed to quantify the amount yield loss resulting from early-season Palmer amaranth interference in rice. The experiment was conducted in a randomized complete block design with a two by five factorial arrangement of treatments with four replications. The first factor consisted of two cultivars of rice, hybrid rice seeded at 6 seed/ft of row and conventional rice seeded at 24 seed/

ft of row. The second factor consisted of different seeding rates of Palmer amaranth spread at 0, 12, 60, 300, and 1500 seeds/m^2. A herbicide program consisting of a recommended rate of clomazone PRE fb fenoxaprop-p-ethyl plus halosulfuron post-flood was applied to all plots to control typical weeds in rice such as barnyardgrass and hemp sesbania. Plots were visually rated for Palmer amaranth control 4 and 5 WAT, and Palmer amaranth counts were taken PREFLD to estimate the number of plants/m^2. Rice was harvested using a small-plot combine. Yield data was subjected to least squares regression analysis. Yield estimates were then determined as a function of cultivar type and Palmer amaranth plants/m^2.

RESULTS AND DISCUSSION

Results from the PRE-applied herbicide programs show that clomazone plus quinclorac PRE provided the best control for Palmer amaranth at 96% and 97% at 2 and 4 WAT, respectively (Table 1). Overall, herbicide programs that included a PRE application controlled Palmer amaranth better than DPRE-only programs. Pendimethalin plus thiobencarb applied DPRE controlled Palmer amaranth 72% at 6 WAT, significantly less than clomazone PRE plus pendimethalin DPRE (86% control 6 WAT) and clomazone PRE plus quinclorac PRE (92% control 6 WAT), suggesting the importance of PRE-applied herbicides for early-season control of Palmer amaranth. Although pendimethalin plus thiobencarb DPRE resulted in rice yields greater than the nontreated check (183 bu/acre compared to 153 bu/acre), it had the lowest yield out of all the herbicide treatments. Clomazone plus imazosulfuron applied PRE resulted in the highest yield of 202 bu/acre. For POST Palmer amaranth control options, propanil plus acifluorfen applied EPOST provided the best control with 98%, 94%, and 85% control at 1, 2, and 4 WAT, respectively (Table 2). These levels of control were significantly greater than for propanil alone applied EPOST. Propanil plus carfentrazone and quinclorac EPOST also provided adequate control of Palmer amaranth at 95% and 94% control at 1 and 2 WAT. Treatments that received the PREFLD application had significantly higher yields than EPOST treatments, with the exception of propanil plus carfentrazone and quinclorac. This is most likely the result of better post-flood control of late emerging barnyardgrass and hemp sesbania with PREFLD treatments versus EPOST treatments. Results from potential yield losses associated with early-season Palmer amaranth interference show that there is a negative relationship between Palmer amaranth density and rice yield. Yields for hybrid rice (247 bu/acre) were on average 18 bu/acrecre higher than conventional rice (220 bu/acre). Regression analysis show that as Palmer amaranth density increased by 10 plants/m^2, yield decreased by 1.3 bu/acre (Fig. 1). In all trials, Palmer amaranth control reached 100% for all treatments once a permanent flood was established, confirming its inability to survive a flooded environment.

SIGNIFICANCE OF FINDINGS

While Palmer amaranth is unable to survive a permanent flood, it has the potential to reduce rice yields through early-season competitive interference. Pre-emergence applied herbicide applications and those in combination with DPRE provided better early-season control than DPRE applications alone stressing the importance of controlling Palmer amaranth before it has a chance to establish. Various EPOST options exist to control Palmer amaranth escapes and should be used in combination with PRE applications. Yield reductions from post-flood interference of barnyardgrass and hemp sesbania show the importance of PREFLD applications and need for season-long weed control programs in rice. In general, herbicide treatments with multiple mechanisms of action performed better at controlling Palmer amaranth than those with a single mechanism of action. To maximize rice yields and reduce herbicide resistance, producers should utilize herbicide programs consisting of multiple mechanisms of action with season-long application timings to control a broad spectrum of weeds including Palmer amaranth.

ACKNOWLEDGMENTS

We would like to thank the Arkansas Rice Research and Promotion Board for funding this research.

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Table 1. Palmer amaranth control from pre-applied rice herbicide programs at Pine Tree Research station near Colt, Ark.

			Palmer amaranth control		
Treatment	Rate	Application timing[†]	2 WAT[‡]	4 WAT	6 WAT
	(lb ai/acre)		-------------------	(%)	------------------
Clomazone	0.3	PRE	91 a[§]	90 b	79 ab
Clomazone	0.3	PRE	95 a	95 ab	86 a
Pendimethalin	1.0	DPRE			
Clomazone	0.3	PRE	95 a	92 ab	82 ab
Imazosulfuron	0.3	PRE			
Clomazone	0.3	PRE	90 a	97 a	80 ab
Thiobencarb	4.0	DPRE			
Pendimethalin	1.0	DPRE	92 a	88 b	72 b
Thiobencarb	4.0	DPRE			
Clomazone	0.3	PRE	96 a	97 a	92 a
Quinclorac	0.5	PRE			

[†] PRE = pre-emergence and DPRE = delayed pre-emergence.

[‡] WAT = weeks after treatment.

[§] Means followed by the same letter are not significantly different according to Fisher's Protected Least Significant Difference test at the 0.05 level.

Table 2. Palmer amaranth control from various early post-emergence herbicide programs in rice at Pine Tree Research Station near Colt, Ark.

		Palmer amaranth control		
Treatment	Rate	1 WAT[†]	2 WAT	4 WAT
	(lb ai/acre)	-------------------------	(%)	-------------------------
Propanil	4.0	82 c[‡]	78 b	45 b
Propanil	4.0	94 ab	90 ab	62 ab
Triclopyr	0.25			
Propanil	4.0	98 a	94 a	85 a
Acifluorfen	0.25			
Propanil	4.0	87 bc	82 ab	68 ab
Carfentrazone	0.016			
Propanil	4.0	95 ab	94 a	81 a
Carfentrazone	0.016			
Quinclorac	0.5			

[†] WAT = weeks after treatment.

[‡] Means followed by the same letter are not significantly different according to Fisher's Protected Least Significant Difference test at the 0.05 level.

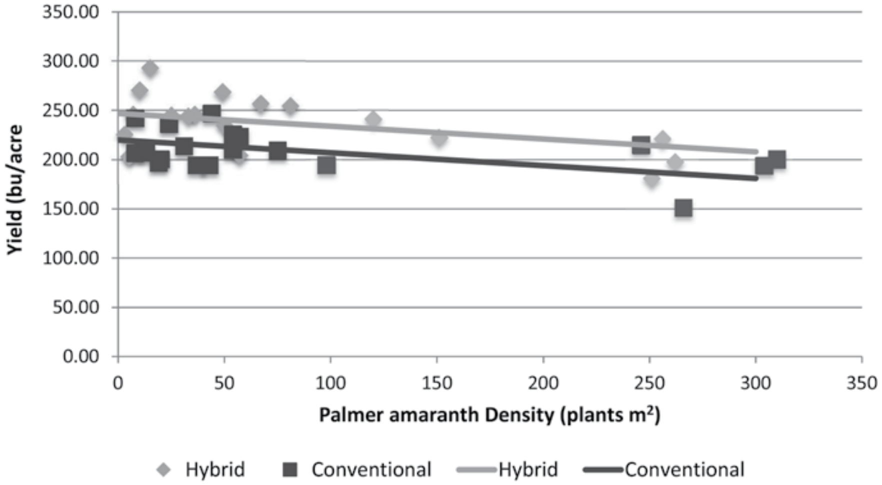

Fig. 1. Early-season Palmer amaranth interference effect on rice yield. Regression lines show the estimated yield reduction by rice type (hybrid and conventional) as Palmer amaranth density increases.

Weed Control Demonstration of Five Rates of Benzobicyclon Applied at Two Maintained Flood Depths to Rice Weeds

B.M. Davis, R.C. Scott., C.A. Sandoski, L.T. Barber, and J.K. Norsworthy

ABSTRACT

Gowan Company has reached an agreement to develop and register the herbicide benzobicyclon for use in U.S. rice. Benzobicyclon is a 4-Hydroxyphenylpyruvate dioxygenase (HPPD) inhibitor that has shown promise controlling certain weeds and rice tolerance. There are currently no HPPD-inhibiting herbicides labeled for use in rice weed control. This demonstration was initiated in the summer of 2013 at the University of Arkansas Pine Bluff Research Station, near Lonoke, Ark., on a Calhoun silt loam soil. This experiment was an unreplicated demonstration. One thing that should be noted is that no rice was planted in this trial. Weed control therefore was evaluated based on the herbicide alone with no rice present to suppress weed growth. Benzobicyclon shows promising control of several problematic rice weeds in Arkansas, including Amazon sprangletop, barnyardgrass, ducksalad, and hemp sesbania. Rate and flood depth are critical to the success of the application, even though means were not separated statistically, a lot can be inferred about this new herbicide.

INTRODUCTION

Gowan Company has reached an agreement to develop and register the herbicide benzobicyclon for use in U.S. rice. Benzobicyclon is a 4-Hydroxyphenylpyruvate dioxygenase (HPPD) inhibitor that has shown promising control of certain weeds and rice tolerance. There are currently no HPPD-inhibiting herbicides labeled for use in rice weed control. Therefore this compound would not only represent a new option for rice producers, but a new herbicide mode of action with activity against resistant weeds such as; barnyardgrass, ducksalad, and nutsedge (Heap, 2014). In particular, acetolactate synthase (ALS)-resistant barnyardgrass and nutsedge pose significant threats to rice production (Riar et al., 2012; Bagavathiannan et al., 2012; Bagavathiannan et al., 2014).

PROCEDURES

This demonstration was initiated in the summer of 2013 at the University of Arkansas Pine Bluff Research Station, near Lonoke, Ark., on a Calhoun silt loam soil. The design was a single replication, with each treatment confined to its own bay, due to the solubility of this compound. Plots were 1.5 m by 7.6 m with levees between treatments. Multiple species of common Arkansas rice weeds were overseeded in the study area prior to levees being pulled. Once weeds reached a height of 10 cm, a permanent flood was established and treatments were applied 24 hours later. Treatment parameters consisted of herbicide rate and flood depths. Two flood depths were maintained daily, at 5-cm and 10-cm deep. Herbicide rates were 0, 124, 186, 248, 309, and 371 g ai/ha. All applications were made using a CO_2-pressurized backpack sprayer calibrated to deliver 93 l/ha. Visual weed control ratings were taken weekly and were estimated using a scale of 0% to 100% where 0 is no control and 100 is complete control.

RESULTS AND DISCUSSION

As early as 18 days after the post application, the 371g ai/ha rate of benzobicyclon was controlling barnyardgrass and Amazon sprangletop 90% at the 10-cm flood depth (Fig. 1). Activity was much slower for broadleaf signalgrass and hemps sesbania which were only being controlled 50% and 70% respectively, at the deeper flood depth. It was already becoming apparent at this time that the deeper flood depth and highest rate of benzobicyclon being evaluated were performing the best in this study.

By 39 days after application, 248, 309, and 371 g ai/ha of benzobicyclon controlled barnyardgrass 95% to 100% regardless of flood depth (Fig. 2). An advantage to a deeper flood was seen at this time at the lower rates (124- to 248-g ai/ha) of the 10-cm flood over the 5-cm flood depth. At this time barnyardgrass was controlled 15% more in a 10-cm than a 5-cm flood by the 248-g ai/ha rate. The highest rate evaluated (371-g ai/ha) was by far the most consistent across species evaluated.

Other species controlled by the 371-g ai/ha rate of benzobicyclon at 39 days after treatment included Amazon sprangletop and ducksalad, which were controlled regardless of flood depth (Fig. 3). Broadleaf signalgrass and hemp sesbania were also controlled by the 371-g ai/ha rate, but only if flood depth was maintained at 10 cm, control of these two weeds dropped sharply in the 5-cm flood.

This experiment was an unreplicated demonstration. One thing that should be noted is that no rice was planted in this trial. Weed control, therefore, was evaluated based on the herbicide alone with no rice present to suppress weed growth. At our location, these types of trials would almost certainly be overrun by aquatics by 40 days after treatment. However, as shown in Fig. 4, there was open water in the 371-g ai/ha plot versus the grown up check to its right. This herbicide appears to have a fit in the early post-emergence (POST)-flood timing area and further evaluation is needed to look at tank-mix partners, the effect of holding or not holding a flood after application and possibly some rate refinement.

SIGNIFICANCE OF FINDINGS

Benzobicyclon shows promising control of several problematic rice weeds in Arkansas, including Amazon sprangletop, barnyardgrass, ducksalad, and hemp sesbania. Rate and flood depth are critical to the success of the application, even though means were not separated statistically, a lot can be inferred about this new herbicide. Studies with replications will be conducted in 2014. Due to the solubility of this compound, replicated trials will be cumbersome as individual bays must be maintained, for each treatment. However, this demonstration has provided us with a rate and the knowledge that this product works and works best under at least a 10-cm flood. This information will help reduce the number of treatments needed in future trials.

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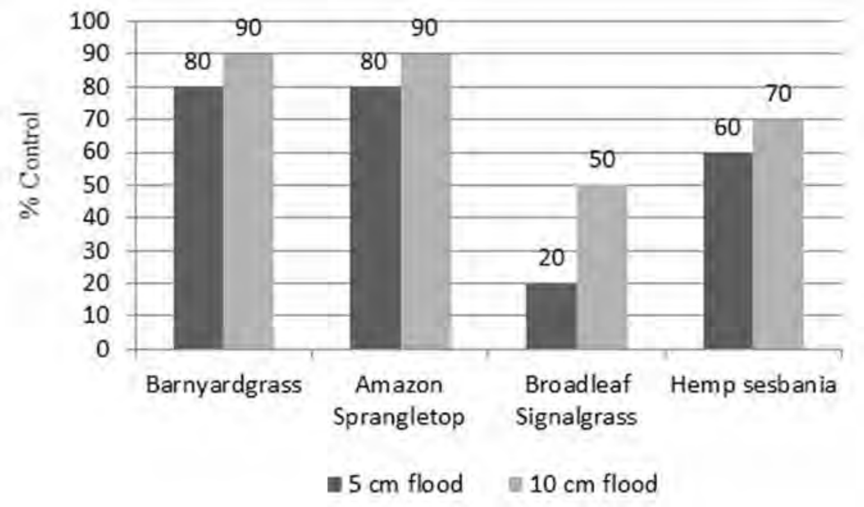

Fig. 1. Control of barnyardgrass, Amazon sprangletop, broadleaf signalgrass, and hemp sesbania with benzobicyclon applied at 371-g ai/ha in both 5- and 10-cm flood at 18 days after application.

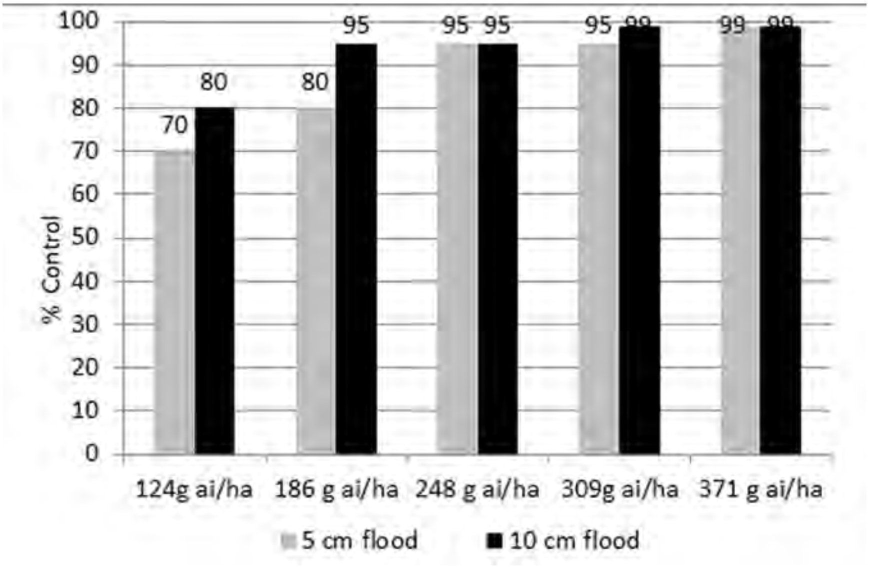

Fig. 2. Barnyardgrass control with two flood depths and with five rates of benzobicyclon evaluated at 39 days after application.

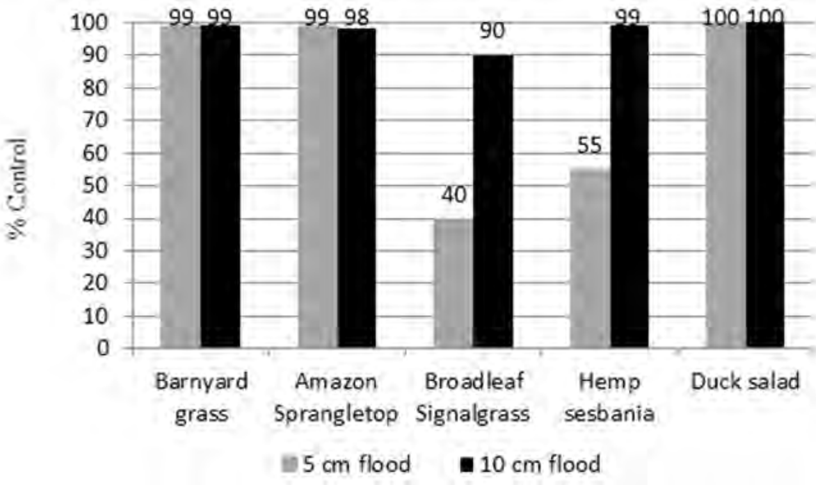

Fig. 3. Weed control with two flood depths with 371-g ai/ha of benzobicyclon evaluated at 39 days after application.

Fig. 4. Photograph taken at 31 days after application of benzobicyclon at 371-g ai/ha (left) at 10-cm flood depth and the untreated check (right).

Response of the Conventional Rice Varieties Roy J and Wells to Low Soil Concentrations of Imazethapyr

J.W. Dickson, R.C. Scott, and B.M. Davis

ABSTRACT

In 2011, the conventional variety Roy J and the conventional hybrid XL723 made up a large percentage of the total conventional rice grown in Arkansas. Many producers assumed that these two varieties were more sensitive to Newpath as many fields of both Roy J and XL723 were found with acetolactate synthase (ALS) or Newpath symptomology. Without side by side comparisons, these claims were not able to be substantiated. The objectives of this research were to compare conventional rice injury between several rice varieties from known amounts of applied Newpath herbicide, and to compare this injury to laboratory results of imazethapyr concentrations of respective soil samples and determine the final impact that these parameters had on rice yield. Cultivars XL723 and Roy J were more tolerant to drift rates of Newpath than were Taggart and Wells. Visual injury and yield of Roy J and Wells was significantly impacted by varying rates of Newpath applied preplant incorporated (PPI) or post-emergence (POST); however, the laboratory results of concentration of imazethapyr in the respective soil samples did not necessarily reflect the amount of injury or yield reduction observed. The concentrations of imazethapyr in soil samples in relation to amounts of Newpath applied, visual rice injury, and yields suggest that simple soil sampling for chemical analysis of imazethapyr concentrations may not be sufficient to correlate rice injury and resulting yield affects.

INTRODUCTION

Approximately 50% of the rice grown in Arkansas is Clearfield™ rice (Hardke and Wilson, 2013). Often this high percentage of Clearfield rice makes conventional rice a target for drift. In 2012, the conventional variety Roy J and the conventional hybrid XL723 made up a large percentage of the total conventional rice grown in Arkansas (Hardke and Wilson, 2013). Many producers assumed that these two varieties were more sensitive to Newpath as many fields of both Roy J and XL723 were found with acetolactate synthase (ALS) or Newpath symptomology. Without side by side comparisons, these claims were not able to be substantiated.

Previous research has fully documented the effects of low concentrations of Newpath herbicide on conventional rice at many rates and timings (Davis et al., 2011; Hensley et al., 2012). Often when drift occurs or injury appears, questions arise as to not only the source of the drift, but also if other factors such as varietal sensitivity or even carryover could be the cause. In addition, soil samples are sometimes taken, the results of which often fail to be interpreted properly; or the specialist asked to advise on the samples has no real data to base their consultations on.

The objectives of this research were to compare conventional rice injury between several rice varieties from known amounts of applied Newpath herbicide, to compare this injury to laboratory results of imazethapyr concentrations in respective soil samples, and to determine the final impact that these parameters have on rice yield.

PROCEDURES

One study to evaluate the response of the conventional hybrid XL723 and the conventional varieties Roy J, Taggart, and Wells to drift rates of Newpath (Study 1), and two studies to evaluate the response of the conventional rice varieties Roy J and Wells to low soil concentrations of imazethapyr (Studies 2 and 3) were conducted near Lonoke, Ark., at the University of Arkansas Pine Bluff Research Station on a Calhoun silt loam (Thermic, Typic, Glossaqualfs) with a pH of 5.4. All studies were initiated following conventional tillage practices. Although not conducted as a split plot, these trials were conducted side by side. In Study 1, three rows each of the conventional hybrid variety XL723, and the conventional varieties Roy J, Taggart, and Wells were planted at a seeding rate of 45 lb/acre into plots 10-ft wide by 25-ft wide by partitioning the hopper of the drill seeder. Treatments in Study 1 consisted of Newpath (active ingredient imazethapyr at a concentration of two lb/gal) applied at the rates of 0.25, 0.5, and 1 oz/acre applied pre-emergence (PRE), and 0.25, 0.5, and 1 oz/acre applied to rice at the 4-lf growth stage. The 4-lf treatments included non-ionic surfactant at 0.25% v/v.

Treatments in Studies 2 and 3 consisted of Newpath applied at the rates of 4 oz/acre (1× labeled rate); 2, 1, 0.5, 0.25, 0.125, and 0.0063 oz/acre applied preplant incorporated (PPI); and at 0.125 and 0.063 oz/acre at the 4-lf rice growth stage. The 4-lf treatments included non-ionic surfactant at 0.25% v/v. Treatments in all studies were arranged in a randomized complete block design with four replications. Herbicide applications were made with a tractor equipped with a multi-boom sprayer and compressed air for propellant, calibrated to deliver 10 gal/acre.

In Studies 2 and 3, the PPI treatments were incorporated to a depth of 4 inches using a John Deere 960 series field cultivator immediately following application. The conventional rice varieties Roy J (in Study 2) and Wells (in Study 3) were drill-seeded at a seeding rate of 95 lb/acre into plots 10-ft wide by 25-ft long. Two days after the 4-lf applications were made (31 May 2013), a soil core 3 inches deep by 4 inches wide from each plot was collected. These soil cores were bulked across all four replications by treatment, placed into plastic bags, and stored in a freezer for approximately 15 days. Each bulked soil sample was analyzed for imazethapyr concentration on 3 July 2013 by South Dakota Agricultural Laboratories (Brookings, S.D.).

Visual rice injury, compared to an untreated check, was assessed using a scale of 0% to 100% (where 0% = no injury and 100% = plant death). Plots were harvested using a John Deere 4435 combine modified for small plot harvesting, and yields were adjusted for moisture content. Data were subjected to analysis of variance using Agriculture Research Manager (ARM9) by Gylling Data Management (Brookings, S.D.), and means were separated using Fisher's Protected Least Significant Difference test ($P = 0.05$).

RESULTS AND DISCUSSION

In Study 1, visual rice injury for all four varieties was minimal (6% or below), 51 days after the PRE applications, regardless of Newpath rate applied (Table 1). Visual rice injury for all four varieties was 83% to 95%, 21 days after the 4-lf application timing at the 1oz/acre Newpath rate, which is 0.25× of the labeled Newpath rate. Many believe the varieties XL723 and Roy J to be more sensitive to Newpath, but this research suggests that these two varieties are more tolerant. The visual injury observed 21 days after the 4-lf application of Newpath at 0.5oz/acre for XL723 and Roy J was 8% and 14%, respectively, while injury ratings for Taggart and Wells were 23%. All non-Clearfield rice varieties are sensitive at some level to exposure to Newpath herbicide. Varieties XL723 and Roy J were actually more tolerant to Newpath than Wells or Taggart.

For Studies 2 and 3, visual rice injury for both Roy J and Wells was expectedly higher in relation to the higher Newpath rates, and decreased in relation to decreasing Newpath rates (Tables 2 and 3). In fact, these two rice varieties responded similarly to all rates of Newpath applied, although no direct comparisons can be made and means are separated by rate for each variety as they were conducted as separate tests. Visual injury to Roy J was 98% and 93% in plots treated with 4 and 2 oz/acre, respectively; and visual injury to Wells was 91% and 75% in plots treated with 4 and 2 oz/acre, respectively. No significant differences were observed between 4 and 2 oz/acre applied PPI for either Roy J or Wells. Visual rice injury, 65 DAT, resulting from Newpath applied 1 oz/acre PPI was 73% and 40% for Roy J and Wells, respectively. For Newpath rates of 0.5 oz/acre and below applied PPI, visual injury was 25% or below, and not significantly different for either variety (Tables 2 and 3).

Yields of Roy J were significantly impacted in relation to corresponding Newpath rates and visual injury ratings (Table 2). The untreated Roy J check yielded 177 bu/acre while 4, 2, and 1 oz/acre rates of Newpath applied PPI resulted in only 11, 22, and 96 bu/acre of rice. Rates of Newpath below 0.5 oz/acre had much less of an impact on rice yield. However, even the next to lowest rate evaluated reduced Roy J yield by 31 bu/acre and was rated as 20% visual injury when applied to 4-lf rice. Only the lowest rate evaluated of 0.063 oz/acre resulted in no yield loss. These yield trends were similar for Wells (Table 3).

The laboratory results of imazethapyr concentrations did not necessarily reflect the amount of visual injury and yield reductions in relation to Newpath rates applied that were observed in these studies. Higher concentrations of imazethapyr were found in plots with the most visual injury and greatest yield reduction. For the two highest rates of Newpath applied (4 and 2 oz/acre PPI), imazethapyr-soil concentrations of 24 ppb and 23 ppb were reported in the study planted with Roy J (corresponding to visual injury of 98% and 93%, respectively) (Table 2), and imazethapyr-soil concentrations of 11 ppm and 2.6 ppm were reported in the study planted with Wells (corresponding visual injury of 91% and 75%, respectively) (Table 3).

It might be expected that imazethapyr-soil concentration would decrease in relation to the decreasing Newpath rates and corresponding visual injury ratings, but this was not the case for these studies. For instance, the imazethapyr soil concentrations from plots treated with 1 and 0.5 oz/acre Newpath PPI were very similar (8.7 ppb and 8.4 ppb, respectively), but visual injury (73% and 20%, respectively) and yields (96 and 138 bu/acre) were significantly different (Table 2). In fact, in both studies, imazethapyr concentrations of 2.3 ppb and 1.2 ppb were present as background noise in samples from the untreated checks planted in Roy J and Wells, respectively, that received no Newpath (Tables 2 and 3).

SIGNIFICANCE OF FINDINGS

All non-Clearfield rice varieties are sensitive at some level to exposure to Newpath herbicide. Some varieties were in-fact more tolerant than others. Contrary to popular belief in 2011, XL723 and Roy J varieties were actually more tolerant to Newpath than Wells or Taggart. These trials confirm the work of others by documenting the detrimental effect that exposure to Newpath can have on non-Clearfield rice (Davis et al., 2011; Hensley et al., 2012).

The concentrations of imazethapyr in soil samples in relation to amounts of Newpath applied, visual rice injury, and yields suggest that simple soil sampling for chemical analysis of imazethapyr concentrations may not be sufficient to correlate rice injury and resulting yield affects. Extremely consistent and carefully taken soil samples along with in-field replication are likely needed to obtain a meaningful result from soil chemical analysis. Many factors could play a part in obtaining such a sample such as contamination of sampling tools, the particular area sampled and how the samples are handled once obtained. Due to the variation observed in the soil concentration data that we obtained in relation to actual injury and yield data, we find these results to be slightly unreliable and should not be depended on solely for determining the source or rate of imazethapyr present in a given field.

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Table 1. Response of four rice varieties to Newpath applied pre-emergence (PRE) and to 4-lf rice.

	Application	Rice injury 51 DAPRE / 21 DAPOS[a]			
Newpath rate	timing	XL723	Roy J	Taggart	Wells
(oz/acre)		----------(%)----------			
0.25	PRE	3	5	5	5
0.5	PRE	3	3	5	6
1	PRE	1	3	3	5
0.25	4-lf	8	14	23	23
0.5	4-lf	6	14	23	23
1	4-lf	83	91	95	95
LSD (*P* = 0.05)	-	6	8	10	11

[a] Abbreviations used: DAPRE = days after pre-emerge applications; DAPOS = days after post-emerge applications.

Table 2. Response of Roy J (visual injury and yield) to seven rates of Newpath applied PPI and two rates applied to 4-lf rice, and resulting soil concentrations of imazethapyr taken 30 days after treatment.

Newpath rate	Application timing[a]	Soil-imazethapyr concentration	Visual injury 65 DAT	Yield
(oz/acre)		(ppb)	(%)	(bu/acre)
0	-	2.3	0	177
4	PPI	24.0	98	11
2	PPI	23.0	93	22
1	PPI	8.7	73	96
0.5	PPI	8.4	20	138
0.25	PPI	4.0	8	143
0.125	PPI	1.0	15	145
0.063	PPI	3.6	13	150
0.125	4-leaf	3.6	20	146
0.063	4-leaf	2.1	10	171
LSD (*P* = 0.05)	-		15	26

[a] Abbreviations used: PPI = preplant incorporated, ppb = parts per billion, DAT = days after treatment.

Table 3. Response of Wells (visual injury and yield) to seven rates of Newpath applied PPI and two rates applied to 4-lf rice, and resulting soil concentrations of imazethapyr taken 30 days after treatment.

Newpath rate	Application timing[a]	Soil-imazethapyr concentration	Visual injury 65 DAT	Yield
(oz/acre)		(ppb)	(%)	(bu/acre)
0	-	1.2	0	91
4	PPI	11	91	6
2	PPI	2.6	75	24
1	PPI	7.0	40	54
0.5	PPI	9.2	19	72
0.25	PPI	2.5	25	83
0.125	PPI	2.2	9	93
0.063	PPI	2.4	5	108
0.125	4-leaf	3.3	20	87
0.063	4-leaf	2.7	9	100
LSD (*P* = 0.05)	-		22	27

[a] Abbreviations used: PPI = preplant incorporated, ppb = parts per billion, DAT = days after treatment.

Rice Tolerance to Sharpen®

J.W. Dickson, R.C. Scott, and B.M. Davis

ABSTRACT

Two studies were conducted in 2012 to evaluate rice tolerance to Sharpen® (saflufenacil), a potential new herbicide for rice. Sharpen is a relatively new product being developed by BASF for use in rice. It is in the protoporphyrinogen oxidase (PPO) inhibiting class of herbicides and has been shown to control many broadleaf weeds in rice, such as, hemp sesbania, annual sedge, and northern jointvetch. However, there has been some concern over crop tolerance issues. In a study designed to evaluate the effect of Sharpen on various rice varieties, no varietal differences were observed in crop response to either 1 or 2 oz/acre of Sharpen applied early post to the varieties CL151, CL111, CL261, and the Clearfield hybrid variety XL745. However, in a second study, crop response of Sharpen was greatly influenced by adjuvant type. The most severe injury was observed when Sharpen was tank-mixed with either methylated seed oil (MSO) or Dyne-Amic, while less injury was observed when Sharpen was used in combination with Agri-Dex or Induce.

INTRODUCTION

Sharpen (saflufenacil) is a protoporphyrinogen oxidase (PPOase)-inhibiting herbicide developed by BASF that provides both contact and rate-dependent residual broadleaf weed control in corn, cotton, rice, small grains, sorghum, soybean, and other situations (Anonymous, 2012). In rice, Sharpen is currently only labeled for preplant burndown of emerged weeds, 15 days prior to planting (Anonymous, 2012). Previous research has indicated that Sharpen is an effective herbicide for post-emergence control of broadleaf weeds that are problematic in rice, such as hemp sesbania (*Sesbania herbacea*) and northern jointvetch (*Aeschynomene virginica*) (Bond and Webster, 2012;

Bond et al., 2011; Camargo et al. 2012; Fickett et al., 2012; Dickson et al., 2008); however, substantial, but temporary, rice injury has been observed from post-emergence applications of Sharpen (Bond et al., 2011; Camargo et al., 2011). Fickett et al. (2012) reported lower rice grain yields in plots treated with Sharpen, although, rice injury was minimal following applications; conversely, Camargo et al. (2012) reported substantial rice injury following applications of Sharpen, but no effect on rice yields. Furthermore, Bond et al. (2011) reported varying levels of rice injury following applications of Sharpen in combination with different adjuvants, but no yield data were presented. Further research is needed prior to a post-emergence label being issued for Sharpen in rice to try to determine what factors may be influencing rice injury following application and if rice grain yields are impacted.

The objectives of this research were to investigate the response of four different rice varieties to Sharpen and the influence of four different types of adjuvants on rice injury and grain yield.

PROCEDURES

A study to evaluate rice response to adjuvant combinations with Sharpen (adjuvant study) and a study to evaluate the response of four rice varieties to Sharpen (variety study) were conducted in 2012 near Lonoke, Ark., at the University of Arkansas at Pine Bluff Research Station on a Calhoun silt loam (Thermic, Typic, Glossaqualfs) with a pH of 5.4. Both studies were planted following conventional tillage practices. The adjuvant study was drill-seeded with the Clearfield hybrid variety XL745 at a seeding rate of 22 lb/acre into plots 10-ft wide by 25-ft long. For the variety study, three rows each of the Clearfield varieties CL151, CL111, CL261, and the Clearfield hybrid variety XL745 were planted at a seeding rate of 50 lb/acre into plots 10-ft wide by 25-ft long by partitioning the hopper of the drill seeder. Treatments in both studies were arranged in a randomized complete block design with four replications. Herbicide applications were made with a tractor equipped with a multi-boom sprayer and compressed air for propellant, calibrated to deliver 15 gal/acre.

The herbicide treatments in the adjuvant study were Sharpen at 1 oz/acre and 2 oz/acre alone, and co-applied with Induce (non-ionic surfactant) 0.25% v/v, Agri-Dex (crop oil concentrate)1% v/v, MSO (methylated seed oil) 1% v/v, and Dyne-Amic (modified vegetable oil surfactant blend) 1% v/v, applied to rice at the 2-lf growth stage (all surfactants manufactured by Helena Chemical Company, Collierville, Tenn.). Aim, also a PPOase inhibiting herbicide, was applied at 1 oz/acre alone, and co-applied with Agri-Dex 1% v/v to rice at the 2-lf growth stage as a comparable treatment. Command (clomazone) at 12.8 oz/acre was applied pre-emergence to all treatments to control grass weeds in the adjuvant study. Plots were harvested using a John Deere 4435 combine modified for small plot harvesting, and yields were adjusted for moisture content.

The herbicide treatments in the variety study were Sharpen at 1 oz/acre and 2 oz/acre plus Agri-Dex 1% v/v, and Aim 1 oz/acre plus Agri-Dex 1% v/v, applied to rice at the 2-lf and 2-tiller growth stages. Newpath (imazethapyr) 4 oz/acre was applied pre-emergence, and Newpath 4 oz/acre tank-mixed with Permit (halosulfuron) 1 oz/acre, Strada (orthosulfamuron) 2 oz/acre, and Agri-Dex 1% v/v was applied preflood to control weeds in the variety study. Visual rice injury, compared to an untreated check, was assessed using a scale of 0 to 100 (where 0 = no injury and 100 = plant death). Data were subjected to analysis of variance using Agriculture Research Manager (ARM8) by Gylling Data Management (Brookings, S.D.), and means were separated using Fisher's Protected Least Significant Difference test ($P = 0.05$).

RESULTS AND DISCUSSION

In the adjuvant study, the treatments with the greatest rice injury contained MSO or Dyne-Amic (Figs. 1-3). Injury ratings at 12 days after treatment (12 DAT) for Sharpen at 1 oz/acre plus MSO or Dyne-Amic were 58% and 43%, respectively, and 45% and 35%, respectively, when the Sharpen rate was increased to 2 oz/acre (Table 1). There were no significant differences at 12 DAT in means comparing Sharpen at 1 oz/acre or 2 oz/acre plus either MSO or Dyne-Amic; however, mean rice injury at 26 DAT was significantly greater for Sharpen at 2 oz/acre plus MSO (43% rice injury), compared to Sharpen at 1 oz/acre plus MSO (18% rice injury). The greatest injury at 12 DAT observed from treatments containing Induce or Agri-Dex was 26% when Sharpen at 1 oz/acre was co-applied with Induce, and 19% when Sharpen at 2 oz/acre was co-applied with Induce. By 26 DAT, rice injury had diminished to 18% or less for all treatments, again, excluding Sharpen (2 oz/acre) co-applied with MSO. No visual rice injury was present, 47 DAT (data not shown). Although there was significant rice injury for some treatments early in the growing season, there were no significant reductions in rice yields. In fact, all plots treated with Sharpen, regardless of rate or adjuvant combination, yielded significantly higher than the untreated check (Table 1). This is probably due to some late emerging hemp sesbania in the check plots that was controlled by the Sharpen in other plots.

Rice injury was negligible in the variety study and did not vary by variety (data not shown). Sharpen at 2 oz/acre plus Agri-Dex injured all varieties 8% when applied to 2-lf rice, and 1% to 2 % when applied to two-tiller rice. All four varieties quickly recovered from visual rice injury, and no injury was observed by 15 DAT; data not shown).

SIGNIFICANCE OF FINDINGS

Although there were no detrimental effects on yield, the high amounts of injury initially observed in the adjuvant study are of concern. The fact that a hybrid rice variety was used in this study, and that this study was maintained under ideal growing conditions (adequate moisture and fertility) more than likely contributed to the rapid recovery from such high amounts of injury. Many times in production agriculture, these ideal growing conditions are not present. This amount of injury could have been greater, and lasted for a longer period of time if adequate moisture and good fertility had not been present, which, in turn, could have made the seedlings more susceptible to infection by diseases, delayed maturity, reduced yields, or all three. Of the adjuvants evaluated, 1% v/v Agri-Dex appeared to cause the least amount of crop injury and impact on grain yield. Initially, a post-emergence label for rice may need to be restricted in terms of which adjuvants are labeled. This data also suggests that rice varieties will respond similarly to Sharpen when Agri-Dex is used as the adjuvant. This research will be repeated in 2013 on a hybrid and conventional rice variety.

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Table 1. Rice injury and grain yields in response to Sharpen with different adjuvant combinations and Aim with and without Agri-Dex.

Treatments[a]	Rice injury 12 DAT[a]	Rice injury 26 DAT	Yield
	------------- (%)	--------------	(bu/acre)
Sharpen 1oz/acre	4	8	225
Sharpen 1oz/acre + Induce 0.25% v/v	26	9	206
Sharpen 1oz/acre + Agri-Dex 1% v/v	6	5	224
Sharpen 1oz/acre + MSO 1%v/v	58	18	235
Sharpen 1oz/acre + Dyne-Amic 1% v/v	43	15	234
Sharpen 2oz/acre	9	8	216
Sharpen 2oz/acre + Induce 0.25% v/v	19	15	226
Sharpen 2oz/acre + Agri-Dex 1% v/v	15	8	243
Sharpen 2oz/acre + MSO 1%v/v	45	43	242
Sharpen 2oz/acre + Dyne-Amic 1% v/v	35	15	236
Aim 1oz/acre + Agri-Dex 1% v/v	6	10	208
Aim 1oz/acre	4	5	199
Untreated check	0	0	172
LSD (*P* = 0.05)	16	16	27

[a] Induce is a non-ionic surfactant, Agri-Dex is a crop oil concentrate, MSO is methylated seed oil, and Dyne-Amic is a modified vegetable oil surfactant blend.

[b] DAT = days after treatment.

Fig. 1. Visual rice injury in a plot treated with Sharpen 1 oz/acre and methylated seed oil 1% v/v, 12 days after treatment.

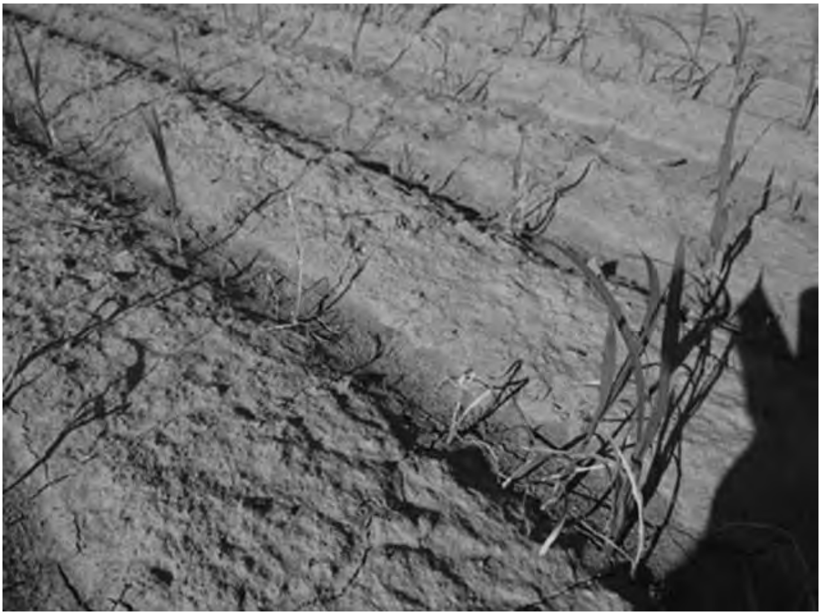

Fig. 2. Visual rice injury in a plot treated with Sharpen 1 oz/acre and Dyne-Amic 1% v/v, 12 days after treatment.

Fig. 3. Rice in an untreated check.

Palmer Amaranth (*Amaranthus palmeri*) Control in Rice

J.R. Meier, L.T. Barber, R.C. Doherty, L.M. Collie, R.C. Scott, and J.K. Norsworthy

ABSTRACT

Palmer amaranth has become a weed of concern for rice producers in Arkansas and Mississippi. Previous control methods of propanil plus Grandstand followed by a deep permanent flood still work, but water conservation practices and application timing have made control more difficult. Some newer herbicides recently labeled in rice may help to control Palmer amaranth. A trial was conducted in 2013 to evaluate Palmer amaranth control in rice with these herbicides. Palmer amaranth control with Sharpen and Sharpen plus Facet L, as well as RicePro, were similar to that of the local standard treatment of Stam M4 plus Grandstand 13 days after application (DAA; preflood). Palmer amaranth control 37 DAA was 99% among all treatments due in part to permanent flood establishment for 3 weeks. Complete control of Palmer amaranth prior to permanent flood establishment reduces the amount of competition between rice and Palmer amaranth, especially for the nitrogen fertilizer applied preflood.

INTRODUCTION

A survey conducted by Norsworthy et al. (2013) listed Palmer amaranth as the fifth most troublesome weed of rice in Arkansas and Mississippi. By 2012, Palmer amaranth was ranked number two, behind barnyardgrass, in a survey of the most common and troublesome weeds of Mississippi rice (Bond, 2012). Palmer amaranth generally will not survive a permanent flood, which is a common practice in rice production, but healthy plants can sometimes survive for 3 or 4 weeks after the permanent flood is established. Water conservation practices in recent years have also added to the rise in Palmer amaranth problems in rice. Due to widespread acetolactate synthase (ALS) resistance in Palmer amaranth populations across Arkansas, and 2,4-D restrictions, control options in rice are limited. The standard recommendation for Palmer amaranth control in Arkansas is to apply Aim or propanil plus Grandstand preflood, then apply a deep flood and hold it (Baldwin, 2011; Scott et al., 2014). A few newer options are now available for use in rice that may provide better control of Palmer amaranth. Sharpen is a newer herbicide labeled for preplant use in rice that currently received a label for post-emergence (after 2-lf) use. Facet L is another herbicide that is a newer formulation of the older Facet DF that was recently labeled for use in rice. RiceBeaux (propanil plus Bolero) and RicePro (propanil plus Facet) are two premixes currently labeled for grass and broadleaf weed control in rice that may also be options for Palmer amaranth control. The purpose of this research was to examine Palmer amaranth control with newer herbicide options in rice.

PROCEDURES

A trial was conducted in 2013 at the University of Arkansas System Division of Agriculture Rohwer Research Station near Rohwer, Ark., to evaluate Palmer amaranth control in rice. A randomized complete block design with four replications was used. The cultivar CL111 was drill-seeded into a Sharkey clay soil at 90 lb/acre, and Palmer amaranth was broadcast-seeded after planting. Treatments were applied with a CO_2 pressurized backpack sprayer calibrated to deliver 10 gal/acre. Palmer amaranth plants were 3 to 6 inches tall, which correlated to one week prior to permanent flood. Palmer amaranth control was evaluated on a scale of 0 to 100 where 0 equals no control and 100 equals complete control 14, 23, and 37 days after application. Data were subjected to analysis of variance and means were separated using Fisher's Protected Least Significant Difference test ($P = 0.05$).

RESULTS AND DISCUSSION

Palmer amaranth control 13 DAA with Stam M4, Grandstand, and Facet L alone was less than combinations of Stam M4 plus Grandstand and Stam M4 plus Facet L or RicePro (Table 1). Sharpen alone or in combination with Facet L, and RicePro provided similar control (98% to 99%) to Stam M4 plus Grandstand (standard recommendation) at this time. RiceBeaux and SuperWham also provided similar control (around 90%), but a few Palmer amaranth escapes can still compete and potentially reduce rice yield. By 23 DAA, the permanent flood had been established for one week and Palmer amaranth control among treatments was similar with the exception of Stam M4 (76%) and Facet L (60%) applied alone. Control with Grandstand alone at this time had improved to 99%, and all other treatments remained relatively unchanged. Palmer amaranth control 37 DAA was 99% among all treatments due in part to permanent flood establishment for 3 weeks.

SIGNIFICANCE OF FINDINGS

Palmer amaranth control with Sharpen and Sharpen plus Facet L, as well as RicePro, were similar to that of the local standard treatment of Stam M4 plus Grandstand 13 DAA (preflood). Complete control of Palmer amaranth at this time reduces the amount of competition between rice and Palmer amaranth, especially for preflood nitrogen fertilizer. Control with Grandstand alone improved with time and flood establishment 23 DAA, and all other treatments followed the same trend by 37 DAA (3 weeks postflood). From this trial, the combination of herbicide treatment and permanent flood can still be used to control Palmer amaranth. However, plants in this study were relatively small (3-6 inches at application) compared to personal field observations. As Palmer amaranth plants get larger, they are harder to control with herbicides and permanent flooding.

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Table 1. Palmer amaranth control at the Rohwer Research Station in 2013.

		Control		
Treatment[a]	Rate	13 DAA[b]	23 DAA	37 DAA
	(unit/acre)	------------------------- (%) -------------------------		
SuperWham	4 qt	94	96	99
COC	1 %			
Ricebeaux	3 qt	90	88	99
COC	1 %			
RicePro	4 qt	98	96	99
COC	1 %			
Stam M4	4 qt	86	76	99
Stam M4	4 qt	99	99	99
Grandstand	1 pt			
NIS	0.25 %			
Stam M4	4 qt	94	94	99
Facet L	1 qt			
COC	1 %			
Sharpen	1 oz	99	99	99
COC	1 %			
Sharpen	1 oz	99	99	99
Facet L	1 qt			
COC	1 %			
Facet L	1 qt	50	60	99
COC	1 %			
Grandstand	1 pt	70	99	99
NIS	0.25%			
LSD (0.05)		12	16	NS

[a] COC = crop oil concentrate and NIS = nonionic surfactant.

[b] DAA = days after application.

Control Options for Acetolactate Synthase-Resistant Smallflower Umbrella Sedge in Arkansas Rice

J.K. Norsworthy, D.S. Riar, R.C. Scott, and T.L. Barber

ABSTRACT

Smallflower umbrella sedge is an increasingly problematic weed in direct-seeded rice in Arkansas. Recently, a sample collected from an Arkansas rice field was confirmed resistant to halosulfuron (Permit). Studies were conducted to determine the effectiveness of various acetolactate synthase (ALS)-inhibiting herbicides on control of the resistant biotype relative to a susceptible biotype and to evaluate alternative herbicide mechanisms of action for control of the resistant biotype. Control of the resistant biotype was <49% with a labeled rate of bispyribac-sodium (Regiment), halosulfuron, imazamox (Beyond), and penoxsulam (Grasp); whereas control of the susceptible biotype was >90% with these herbicides. Control of both biotypes was >96% with bentazon (Basagran) and propanil (Riceshot), but quinclorac (Facet), thiobencarb (Bolero), and 2,4-D (Weedar) were ineffective. Considering propanil-resistant smallflower umbrella sedge has been confirmed in California, it would be prudent to tank-mix bentazon and propanil to minimize further risk of resistance evolving to these herbicides in Arkansas rice.

INTRODUCTION

Sedges, mainly yellow nutsedge and rice flatsedge, are common in Arkansas rice fields but are not among the most problematic weeds (Norsworthy et al., 2013) most likely because acetolactate synthase (ALS)-inhibiting herbicides and propanil are often effective (Scott et al., 2013). To a lesser extent, smallflower umbrella sedge is present in Arkansas rice fields, and until recently, it has not been a weed of concern. In 2010, halosulfuron (Permit) failed to control smallflower umbrella sedge in an Arkansas rice field, and the population was later confirmed resistant to halosulfuron in a greenhouse screening conducted the same year. This is not the first case of a smallflower umbrella sedge biotype evolving resistance to ALS-inhibiting herbicides. Actually, ALS-resistant smallflower umbrella sedge populations have been confirmed in other rice-growing regions of the world (Osuna et al., 2002; Graham et al., 1996; Kuk et al., 2004). In California, smallflower umbrella sedge is a common weed of rice having widespread resistance to ALS-inhibiting herbicides and most recently confirmed resistance to propanil (Pedroso et al., 2013).

Bensulfuron (Londax), halosulfuron, and orthosulfamuron (Strada) are sulfonylurea herbicides (ALS inhibitors) applied to rice as part of a broadleaf and sedge weed control program. Over-reliance on ALS-inhibiting herbicides for sedge control has led to evolution of resistance within sedges other than smallflower umbrella sedge, including rice flatsedge and yellow nutsedge. For rice flatsedge, the level of resistance to halosulfuron was more than 480-fold (Norsworthy, unpublished data). Initial evaluations on smallflower umbrella sedge also indicate a high level of resistance to halosulfuron in this closely related species. In regards to herbicide options for control, bentazon, propanil, and 2,4-D are recommended for ALS-resistant rice flatsedge, but the effectiveness of these and other herbicides on halosulfuron-resistant smallflower umbrella sedge is not known (Scott et al., 2013).

Experiments were conducted to assess the effectiveness of ALS-inhibiting herbicides from several herbicide families on resistant as well as susceptible smallflower umbrella sedge biotypes and to evaluate currently labeled alternative herbicide mechanisms of action for control of both biotypes.

PROCEDURES

Seeds of the halosulfuron-resistant smallflower umbrella sedge biotype were collected from a production field in southeast Arkansas that had been in continuous rice for at least 10 years. Seeds of a confirmed ALS-susceptible smallflower umbrella sedge biotype were obtained from California. Seeds of both biotypes were sown in the greenhouse in separate trays and emerged seedlings at the 3- to 4-lf stage were treated with halosulfuron at 0.75 oz ai/acre to ensure that all resistant plants would survive and all susceptible plants would be controlled by the herbicide.

Four halosulfuron-resistant and -susceptible smallflower umbrella sedge plants each at 1- to 2-lf stage were transplanted into separate 6-inch diameter pots. At the 3- to 4-lf stage, resistant and susceptible plants were treated with one of five ALS-inhibiting herbicides, which included halosulfuron at 0.75 oz ai/acre, bispyribac-sodium (Regiment) at 0.5 oz ai/acre, imazamox (Beyond) at 0.5 oz ai/acre, imazethapyr (Newpath) at 1.0 oz ai/acre, and penoxsulam (Grasp) at 0.7 oz ai/acre. Halosulfuron, imazamox, and imazethapyr treatments contained nonionic surfactant (Induce) at 0.25% v/v; whereas bispyribac-sodium was applied with a nonionic spray adjuvant and deposition aid (Dyne-A-Pak) at 2.5% v/v and penoxsulam contained crop oil concentrate (Agri-Dex) at 1% v/v. All treatments were applied using a compressed air spray chamber having a boom fitted with two flat fan 800067 nozzles calibrated to deliver 20 gal/acre at 40 psi.

A similar setup was used to evaluate the effectiveness of alternative herbicide mechanisms of action for control of smallflower umbrella sedge biotypes. The herbicides tested in this experiment included bentazon (Basagran) at 0.75 lb ai/acre, propanil (Riceshot) at 4.0 lb ai/acre, quinclorac (Facet) at 0.5 lb ai/acre, thiobencarb (Bolero) at 4.0 lb ai/acre, and 2,4-D (Weedar) at 0.95 lb ae/acre.

After applying the herbicides, all pots were watered daily and once weekly with a water-soluble fertilizer. Smallflower umbrella sedge control was visually estimated 21 d after treatment (DAT) on a scale of 0 (no control) to 100 (complete plant mortality) and aboveground biomass was subsequently harvested the same day, dried, and weighed. Plant dry weight was expressed a percent of the nontreated control.

Both experiments were conducted in a randomized complete block design. The first experiment was a two (resistant and susceptible biotypes) by five (ALS-inhibiting herbicides) factorial and the second was likewise a two (resistant and susceptible biotypes) by five (alternative non-ALS herbicides) factorial arrangement. Each experiment contained four replications (16 plants per treatment with four plants per replication), and each experiment was repeated. Percent control and dry weight data were subjected to arcsine square root transformation before analyses to improve normality. Transformed data were subjected to analysis of variance using PROC MIXED in SAS (SAS Institute, Inc., Cary, N.C.) to evaluate the effect of different herbicides on control and dry weight of halosulfuron-resistant and -susceptible smallflower umbrella sedge. Data from the repeated experiments were pooled because of nonsignificant treatment-by-experiment interactions. Means were separated using Fisher's Protected Least Significant Difference (LSD) test $P = 0.05$. Additionally, resistant and susceptible biotypes were compared within a herbicide. Interpretation of results was similar with transformed and nontransformed data; thus, nontransformed means are reported.

RESULTS AND DISCUSSION

Control of the susceptible biotype with bispyribac-sodium, halosulfuron, imazamox, imazethapyr, and penoxsulam was >90% (Table 1). In contrast, control of the resistant biotype ranged from 6% to 49% for the ALS herbicides evaluated. Dry weight reduction was similar to the control estimates for both biotypes for each herbicide (data not shown).

This is the fourth weed of rice to have evolved resistance to ALS-inhibiting herbicides in Arkansas, of which the others are barnyardgrass, rice flatsedge, and yellow nutsedge (Riar et al., 2012; 2013). In regards to smallflower umbrella sedge, cross resistance to ALS-inhibiting herbicides has been reported previously for accessions from California (Osuna et al., 2002). Smallflower umbrella sedge is not a common weed of Arkansas rice; hence, whether this resistant biotype was introduced from other geographies or evolved independently as a result of repeated use of ALS herbicides is not known at this time.

Control did not differ between biotypes for any of the alternative non-ALS herbicides evaluated (Table 2). Bentazon and propanil were the only herbicides to provide effective control of both biotypes. Similar to the findings here, ALS-resistant and -susceptible smallflower umbrella sedge biotypes in Brazil were effectively controlled with bentazon (Galon et al., 2008). Propanil is recommended for a wide variety of sedges in Arkansas rice (Scott et al., 2013); however, it should be noted that propanil-resistant populations exist in California (Pedroso et al., 2013); hence, the most appropriate control tactic for smallflower umbrella sedge is likely a tank-mix of propanil plus bentazon.

SIGNIFICANCE OF FINDINGS

This research documents the existence of smallflower umbrella sedge in Arkansas having resistance to at least four herbicide chemical families, all of which are classified as ALS inhibitors. Sustaining utility of alternative herbicides that are currently effective should be of paramount importance. Most certainly, controlling resistant smallflower umbrella sedge with alternative herbicides will add to current weed management costs for producers. Based on this research, propanil and bentazon are both effective alternatives, but steps must be taken to minimize selection pressure on these two herbicides if effective control options are to be sustained.

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Table 1. Control of halosulfuron-resistant and -susceptible smallflower umbrella sedge with applications of acetolactate synthase-inhibiting herbicides labeled for use in conventional or Clearfield rice at 21 days after treatment.

		Control	
Herbicide	Rate	Susceptible	Resistant
	(oz ai/acre)	------------------(%)-----------------	
Bispyribac-sodium	0.5	95 Ab[†]	6 Bc
Halosulfuron	0.75	100 Aa	24 Bb
Imazamox	0.5	90 Ac	6 Bc
Imazethapyr	1.0	96 Ab	7 Bc
Penoxsulam	0.7	98 Aab	49 Ba

[†] Means for each herbicide within a row followed by the same uppercase letters and mean for each accession within a column followed by the same lowercase letters are not significantly different according to Fisher's Protected Least Significant Difference test (P = 0.05).

Table 2. Control of halosulfuron-resistant and -susceptible smallflower umbrella sedge with rice herbicides at 21 days after treatment.

		Control	
Herbicide	Rate	Susceptible	Resistant
	(lb ai/acre)	-------------------(%)-----------------	
Bentazon	0.75	98 Aa[†]	96 Ab
Propanil	4.0	100 Aa	100 Aa
Quinclorac	0.5	13 Ac	17 Ac
Thiobencarb	4.0	23 Ab	4 Ad
2,4-D	0.95[‡]	21 Ab	18 Ac

[†] Means for each herbicide within a row followed by the same uppercase letters and mean for each accession within a column followed by the same lowercase letters are not significantly different according to Fisher's Protected Least Significant Difference test (P = 0.05).

[‡] The herbicide rate for 2,4-D is reported as acid equivalents (ae) rather than active ingredient (ai).

Use of CruiserMaxx® Rice Seed Treatment to Improve Tolerance of Conventional Rice to Newpath (Imazethapyr) and Roundup (Glyphosate) at Reduced Rates

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ABSTRACT

The occurrence of glyphosate (Roundup) and imazethapyr (Newpath) herbicide drift on conventional rice has become a problem in recent years. In some instances, it has been observed that rice plants having an insecticide seed treatment are more tolerant to herbicide drift than rice plants that do not have an insecticide seed treatment. A trial was conducted in 2013 to evaluate the effect of the insecticide seed treatment CruiserMaxx Rice on exposure of young conventional rice (Roy J) to the herbicides Roundup and Newpath. The objective of this study was to evaluate the effects of Roundup and Newpath drift on rice with and without an insecticide seed treatment. 'Treated seed' received 7 oz/cwt of CruiserMaxx Rice, an insecticide seed treatment (thiamethoxam) plus a fungicide seed treatment mixture; and 'untreated seed' received only the fungicide seed treatment mixture (no insecticide). Newpath rates evaluated were 0.25, 0.5, and 1.0 oz/acre; Roundup rates evaluated were 1.0, 2.0, and 4.0 oz/acre. Herbicide treatments were applied to 3- to 4-leaf (lf) rice. Newpath applied at 0.5 oz/acre caused over 50% more visual injury at 42 days after treatment and resulted in a 100 bu/acre yield decrease for untreated rice versus treated rice exposed to the same rate of Newpath. Similarly, rice with treated seed exposed to 4 oz/acre of Roundup yielded 70 bu/acre more than rice with untreated seed. Positive effects of the insecticide seed treatment on rice growth parameters were seen in days to heading, canopy height, visual injury ratings, and grain yield at all rates evaluated for both herbicide products.

INTRODUCTION

Currently over 50% of the rice grown in Arkansas is planted to Clearfield rice which is tolerant to applications of the herbicides Newpath (imazethapyr) and Beyond (imazamox) (Hardke and Wilson, 2013; Wilson et al., 2010). The remainder of the rice grown in the state lacks the Clearfield tolerance trait and is therefore susceptible to injury if Newpath or Beyond is somehow applied to the field either through tank-contamination, drift, or by accidental application. In addition, there are over 3 million acres of soybeans grown in Arkansas in close proximity to rice. The majority of these soybeans are Roundup Ready and receive applications of the herbicide Roundup (glyphosate). Previous research has shown that both Newpath and Roundup can be harmful to rice yields depending on rate and timing of exposure (Davis et al., 2011; Hensley et al., 2012).

In previous research, York et al. (1991) found that disulfoton and phorate greatly reduced clomazone injury to cotton when applied in-furrow. Similar results with the in-furrow applications of phorate were also documented; however not for the insecticide aldicarb in 1990 and 1991 (York and Jordan, 1992). Both these reductions in crop injury were observed in the relative absence of insect pressure. This effect was later quantified in the lab by Culpepper et al. (2001). They determined that this 'safening effect' was due to the insecticide causing a change in the metabolism of clomazone in cotton, suggesting that some clomazone metabolite may be more toxic to cotton than the compound itself. Nonetheless, this work does represent a precedent for using a soil or in-furrow insecticide treatment to 'safen' a crop to a given herbicide. In fact, this was a common practice throughout the mid-to-late 1990s and early in the 2000s in cotton production prior to the introduction of Roundup Ready™ Cotton (Culpepper et al., 2001).

Wilf et al. (2010) and later Plummer et al. (2012) documented many benefits of insecticide seed treatments in rice. Some of these benefits include overall improved plant vigor that may or may not be due to insect pressure but to other biological processes inside young rice seedlings as they are affected by the presence of the insecticide. In 2010 and again in 2011, observations were made by Dr. Gus Lorenz, State Extension Entomologist, University of Arkansas System Division of Agriculture, that some of his insecticide seed treatment rice plots were able to tolerate an accidental herbicide drift from an adjacent field while those without an insecticide seed treatment were less tolerant (pers. comm. and observations). The ability to safen rice to potential herbicide drift or injury from other herbicides would be a valuable benefit for rice producers today. This seems to be especially true as seeding rates are lowered for many rice cultivars.

The objective of this research was to evaluate the potential for CruiserMaxx Rice insecticide seed treatment to protect conventional rice (Roy J) from both Newpath and Roundup exposure.

PROCEDURES

This experiment was conducted at the University of Arkansas Pine Bluff Research Station, near Lonoke, Ark., in the summer of 2013. The soil is a Calhoun silt loam with a pH of 6.3. Conventional rice (Roy J) was planted on 31 April 2013 with a Hege

(Wintersteiger, Inc. Salt Lake City, Utah) cone drill calibrated to deliver a seeding rate of 90 pounds (lb)/acre on 7.5-inch rows. Plot size was 5 ft × 25 feet. The study was conducted with a randomized complete block design having four replications.

Treatments consisted of seed treatment and herbicide combinations. The seed treatments consisted of 'treated seed' on which CruiserMaxx Rice at 7 oz/cwt of seed was applied. CruiserMaxx Rice contains the insecticide thiamethoxam (26.4%) and the fungicides mefenoxam (1.65%), azoxystrobin (1.32%), and fludioxonil (0.28%). The second seed treatment was considered the 'untreated seed' which actually received equivalent amounts of the fungicides azoxystrobin, mefenoxam, and fludioxonil as the treated seed but without the insecticide thiamethoxam.

The herbicide treatments were applied at the 3- to 4-lf growth stage of rice with a CO_2 backpack sprayer calibrated to deliver 10 gallons of spray solution per acre. Herbicide treatments included Roundup (5.5 lb ai/gal formulation) applied at 1.0, 2.0, and 4.0 oz product/acre and Newpath 2AS (2 lb ai/gal formulation) applied at 0.25, 0.5 and 1.0 oz product/acre and an untreated control. The plot area was maintained weed free with conventional rice herbicides and the rice was grown according to University of Arkansas Cooperative Extension Service recommendations for soil fertility.

Data collected included: percent visual injury at 7, 21, and 42 days after treatment (DAT); canopy heights at 68 DAT, percent rice heading at 107 DAT, percent moisture, and grain yield. Data were analyzed and least significant differences generated at the $P = 0.05$ level of significance using ARM 9.1.4 (Gylling Data Management, Brookings, S.D.).

RESULTS AND DISCUSSION

As early as 7 DAT, both Newpath and Roundup were causing visual injury to rice. Plants grown from the untreated rice seed were injured by Roundup from 13% to 33% depending on rate and this injury was significantly lower compared to rice with treated seed when the low rate of Roundup (1.0 oz/acre) was evaluated at this time (Table 1). Newpath also caused injury ranging from 23% to 33% at 7 DAT. As with the Roundup treatments, injury from Newpath was already visually lower on rice plants with treated seed, especially at the low rate (0.25 oz/acre), where rice was injured 20% less when seed was treated with the insecticide thiamethoxam. Injury symptoms included stunting and chlorosis (yellowing).

By 21 DAT, injury symptoms had become more pronounced for all treatments. Both rice from treated and untreated seed were injured over 90% by Newpath at 1.0 oz/acre. However, some differences were also becoming more pronounced. For example, where Newpath was applied to rice plants grown from untreated seed it injured rice 43% versus only 16% for rice plants grown from treated seed. Roundup at 4.0 oz/acre injured rice with treated seed 15% less than rice when seed was untreated.

Although injury had been equal for Newpath applied at 1.0 oz/acre to rice from both treated and untreated seed at 21 DAT, by 42 DAT treated seed rice had recovered and injury for treated versus untreated was 58% and 97%, respectively. Other herbicide seed treatment interactions were even more pronounced at 42 DAT. Newpath applied at 0.25 oz/acre to rice with treated seed was rated zero at this time versus 26% for rice with untreated seed. Injury from this rate of Newpath to plants grown from untreated rice seed was consistently rated at 25% for the duration of the test. At 0.5 oz/acre Newpath, injury to rice with treated seed had dropped to 6%, versus 63% for untreated seed. Roundup applied at 4.0 oz/acre resulted in 53% injury to the rice with untreated rice seed versus only 10% for plants when rice seed was treated.

Treatment differences were also observed in canopy height taken at 68 DAT (Table 1). Rice plants that did not receive any herbicide treatment, regardless of seed treatment grew to a canopy height of 34.6 inches. Canopy heights were taken using a yard stick and a 39.4-inch (1-meter) square piece of cardboard in a method previously described by Davis et al. (2011). Newpath reduced canopy height at the 0.5 and 1.0 oz/acre rates by 15.7 inches and 34.6 inches, respectively, when applied to rice with untreated seed. For rice receiving the 1.0 oz/acre Newpath treatment, there were not enough rice plants in the test plots with untreated seed to record a canopy height due to the severity of the stand reduction. However, the rice grown from treated seed survived 1.0 oz/acre of Newpath and resulted in a canopy height of 29.9 inches, not statistically different from the control (34.6 inches).

Roundup in general did not affect canopy height as severely as Newpath. Both treated and untreated rice plants sprayed with 1.0 or 2.0 oz/acre Roundup produced canopy heights from 34.2 inches to 37.8 inches in height, not statistically different from the control. However at the 4.0 oz/acre rate, the rice in plots with untreated seed grew to 22.8 inches, while rice plants with treated seed reached a normal height of 35.8 inches for this test by 68 DAT (Table 1).

Percent heading and moisture data and grain yields were obtained at 107 DAT in this study. For purposes of this study, a common harvest date was selected to simulate a decision that a grower might have to make as to when to harvest a field with varying degrees of injury. For this reason the above mentioned harvest parameters might have been slightly different if, for example, some of the more severely injured plots were given more time to mature and dry down. Likewise, the less injured plots could have been harvested sooner. However, due to study design this was not practical. Therefore a single harvest date was chosen based on a time when the majority of plots were ready.

Percent heading was taken as a visual rating based on the non-herbicide treated checks, which were both 100% headed at 107 DAT (Table 1). The only rice that received an insecticide seed treatment and had delayed heading was the 1.0 oz/acre Newpath treatment which reduced heading about 40% compared to the check. All other plots that received the insecticide thiamethoxam in the seed treatment resulted in 95% to 100% heading at the time evaluated. Newpath generally delayed heading or prevented heading to a more severe degree than glyphosate on untreated seed plants compared to treated seed plants. Newpath at 0.25, 0.5, and 1.0 oz/acre resulted in 20%, 42%, and 52% reductions in rice heading, respectively, at 107 DAT on untreated seed.

At harvest, in addition to grain yield, percent moisture was determined for each treatment. There was a tremendous amount of variation among the herbicide treated plots which resulted in few statistical differences. The non-herbicide treated checks were 22% grain moisture at harvest. With an LSD of 8, few of the treatment differences were significant. Results like these can be common when dealing with rates of herbicides applied far below the labeled rates (Davis et al., 2011; Hensley et al., 2012).

Grain yield of rice ranged from 17 to 170 bushels (bu)/acre with an LSD (0.05) of 25 bu for this experiment. Rice from untreated seed with no herbicide yielded 147 bu/acre while the insecticide treated control yielded 169 bu/acre. When Newpath herbicide was applied at either 0.25 or 0.5 oz/acre, the resulting yields were 100 bu/acre higher for rice with the insecticide seed treatment versus the rice where the seed was untreated or only treated with the fungicide. However at the 1.0 oz/acre rate, even the rice with treated seed resulted in only 45 bu/acre compared to 17 bu/acre for the rice with untreated seed. These results suggests that there is a limit to thiamethoxam's ability to 'safen' rice to Newpath.

All rice with an insecticide seed treatment yielded higher than rice with the untreated (fungicide only) seed when exposed to Roundup. This difference was most pronounced at the 4.0 oz/acre rate of Roundup where yield was improved by over 60 bu/acre with the addition of a seed treatment that included thiamethoxam.

SIGNIFICANCE OF FINDINGS

The ability of an insecticide seed treatment to enable young rice plants to better tolerate off-target drift of both Newpath and Roundup could significantly reduce the number of complaint investigations requested by growers to both the Arkansas State Plant Board and the Cooperative Extension Service. The resulting higher yields as rice injury is reduced are not only a benefit to growers, but also to those responsible for the off-target movement. Although more research is needed, the ability of an insecticide seed treatment to improve tolerance of certain Clearfield hybrids such as XL745 would be of benefit under cool, wet conditions especially with reduced seeding rates. With half of the rice grown in Arkansas planted to Clearfield cultivars, this research could make it more plausible and less troublesome to applicator's and growers when these cultivars are planted in close proximity to those lacking the technology.

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Table 1. Effect of Newpath and Roundup at reduced rates on rice injury, plant canopy height, heading date, percent grain moisture, and yield when applied to insecticide treated versus untreated Roy J rice seed at the University of Arkansas Pine Bluff Research Station, near Lonoke, Ark., in 2013.

Treatment	Herbicide rate	Visual injury 7 DAT[a]	Visual injury 21 DAT	Visual injury 42 DAT	Height 68 DAT	Heading 107 DAT	Moisture 107 DAT	Grain yield
	(oz/acre)	(%)	(%)	(%)	(inches)	(%)	(%)	(bu/acre)
Nontreated[b]	0	0	0	0	34.6	100	22	147
Treated[c]	0	0	0	0	34.6	100	22	169
Nontreated - Newpath	0.25	25	25	26	30.3	80	24	70
Treated - Newpath	0.25	5	8	0	36.2	100	22	170
Nontreated - Newpath	0.50	23	43	63	21.2	58	13	136
Treated - Newpath	0.50	21	16	6	32.3	95	23	37
Nontreated - Newpath	1.0	33	92	97	-	48	-	45
Treated - Newpath	1.0	18	95	58	29.9	63	19	17
Nontreated - Roundup	1.0	19	9	13	37.8	83	23	104
Treated - Roundup	1.0	3	3	0	35.0	98	24	148
Nontreated - Roundup	2.0	13	14	11	32.3	90	17	113
Treated - Roundup	2.0	10	9	0	34.2	95	23	144
Nontreated - Roundup	4.0	33	36	53	22.8	78	22	59
Treated - Roundup	4.0	33	19	10	35.8	95	23	128
LSD (*P* = 0.05)		15	15	21	7.9	9	8	25

[a] DAT = days after treatment.

[b] Nontreated refers to seed that did not receive an insecticide seed treatment but did receive a fungicide seed treatment (azoxystrobin, mefenoxam, and fludioxonil).

[c] Treated refers to seed that received CruiserMaxx Rice containing an insecticide seed treatment (thiamethoxam) in addition to a fungicide seed treatment (azoxystrobin, mefenoxam, and fludioxonil).

Evaluation of Conventional and Hybrid Rice, Seeding Rate, and Herbicide Program on Barnyardgrass Control in Clearfield Rice

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ABSTRACT

Barnyardgrass, the most problematic weed of rice (*Oryza sativa* L.), has evolved resistance to a number of herbicide mechanisms of action. It infests almost all rice fields in the state, lowering yields and grain quality. Adopting integrated management practices including cultural and diverse herbicide options may reduce the selection pressure for the evolution of herbicide resistance in barnyardgrass. A field trial was conducted at the University of Arkansas System Division of Agriculture Rice Research and Extension Center near Stuttgart, Ark., in 2013 to evaluate the impact of Clearfield rice cultivars (CL152 and hybrid XL745) and seeding rates (0.125×, 0.25×, 0.5×, 1×, 2×, and 4× the recommended seeding rates) on barnyardgrass control (%) and panicle count (an estimate of seed production) under two herbicide programs {Program #1 [pre-emergence (PRE) followed by (fb) post-emergence (POST)]: Command (PRE) fb Newpath early post-emergence (EPOST) fb Newpath preflood (PREFLD) fb Beyond postflood (POSTFLD)}; Program #2 (POST only) - Newpath (EPOST) fb Newpath (PREFLD) fb Beyond (POSTFLD). Rice cultivars did not influence barnyardgrass control and panicle production but seeding rate >0.25× did. Inclusion of a PRE herbicide such as Command resulted in a high level of barnyardgrass control and reduced potential seedbank addition from barnyardgrass escapes. Using PRE herbicides in the program can in turn reduce selection pressure on the POST herbicide applications. Thus, inclusion of an effective PRE herbicide and high seeding rate, rather than selecting cultivars was found to be useful in achieving effective barnyardgrass control and reducing the selection pressure of POST herbicides on these populations.

INTRODUCTION

Broad-spectrum herbicides remain at the core of the basic weed control technology in Arkansas rice since the late 1950s (Smith, 1961). Barnyardgrass (*Echinochloa crus-galli*) is a summer annual herbaceous weed and is the sixth prominent herbicide-resistant weed in the world (Heap, 2014). It is the most troublesome weed of Arkansas rice, having resistance to multiple herbicide mechanisms of action (Norsworthy et al., 2013). Currently, barnyardgrass populations in Arkansas have evolved resistance to most of the herbicides that have been relied upon heavily to provide effective control, including Riceshot (propanil), Facet (quinclorac), Command (clomazone), and acetolactate synthase (ALS) inhibitors such as Newpath (imazethapyr) (Carey et al., 1995; Lovelace et al., 2000; Norsworthy et al., 2009; Riar et al., 2012). Command is a pre-emergence (PRE) herbicide that is primarily effective on annual grasses in rice including barnyardgrass. Repeated application of this herbicide led to the evolution of clomazone-resistant barnyardgrass (Norsworthy et al., 2008), albeit only two populations have been found to date. Commercialization of Clearfield rice in the mid-South has allowed for increased use of ALS-inhibiting herbicides in rice. Due to the rapid loss of herbicide options for effective barnyardgrass control in rice, there is a critical need to integrate non-chemical weed management options in Clearfield rice.

Increasing crop seeding rates can be an important non-chemical strategy in reducing weed biomass and minimizing selection for herbicide resistance. In this study, the ability of Clearfield rice cultivars (hybrid vs conventional) to suppress barnyardgrass was evaluated across a wide array of rice seeding rates for each cultivar. It was hypothesized that increasing rice seeding rate and use of clomazone as a PRE-applied herbicide in Clearfield rice would reduce the selection pressure imposed by post-emergence (POST)-applied ALS-inhibiting herbicides through a reduction in barnyardgrass seed production.

PROCEDURES

The experiment was conducted at University of Arkansas System Division of Agriculture Rice Research and Extension Center near Stuttgart, Ark., in 2013. The soil was a Dewitt silt loam, and the trial was conducted in a randomized complete block design with two (rice cultivars), by six (rice seedling rates), by three (herbicide programs) factorial arrangement of treatments and four replications. Clearfield 152, a conventional variety (recommended seeding rate = 24 seed/row ft), and Clearfield XL745, a hybrid (6 seed/row ft), were planted at 0.125 to 4 times (×) their respective recommended seeding rates (0.125×, 0.25×, 0.5×, 1×, 2×, and 4×). Each plot measured 6 ft by 20 ft and rice was planted using a 9-row drill with 7-inch row spacing. Herbicide treatments included either a PRE application of Command at 0.3 lb ai/acre followed by (fb) an early post-emergence (EPOST) as well as preflood (PREFLD) applications of Newpath at 0.063 lb ai/acre and a postflood (POSTFLD) application of Beyond (imazamox) (program #1) at 0.04 lb ai/acre or a POST-only program similar to Program #1, excluding the PRE herbicide application. All POST applications included adjuvants.

Both rice cultivars were planted on 8 May 2013 immediately followed by the PRE application of command. A CO_2-pressurized backpack sprayer fitted with a handheld boom equipped with four TTI 110015 nozzles was used for all herbicide applications. Herbicides were applied at 3 mph, and the boom was calibrated to deliver 15 gal/acre at 40 psi. Environmental conditions at planting and subsequent days were conducive for rice germination; hence rice densities determined at 20 days after planting (DAP) were reflective of seeding rates. At 20, 50, and 141 DAP, barnyardgrass control was visually rated on a scale of 0 (healthy plants) to 100 (complete plant death) scale. Immediately prior to rice harvest, barnyardgrass panicles were counted in each plot.

Data were analyzed using the statistical analysis software (SAS, v. 9.3.1; SAS Institute, Inc., Cary, N.C.). Main factor effects and their interactions were evaluated using analysis of variance (ANOVA) using PROC MIXED in SAS. Data were transformed to meet the assumptions of ANOVA.Means were separated using Fisher's Protected Least Significant Difference test at $P = 0.05$.

RESULTS AND DISCUSSION

The program that included command at PRE resulted in 97% to 99% barnyardgrass control at 20 DAP (data not shown), suggesting a substantial reduction in the selection pressure on subsequent POST herbicide applications. Conventional rice had higher rice stands at 20 DAP compared to hybrid (planted at 0.25× rate of conventional rice) for all seeding rates, but herbicide programs did not influence rice density. In PRE (fb) POST treatments, barnyardgrass control at 50 DAP (average over seeding rate) was 98%, whereas control was only 93% in the POST-only program (data not shown). Although, barnyardgrass control was significantly different for both cultivar and seeding rate, no difference was observed between herbicide programs at 50 DAP. This suggests that the imazethapyr in POST-only treatment provided similar control compared to clomazone applied PRE. The POSTFLD-application of imazamox increased barnyardgrass control, at 141 DAP for both cultivars (data not shown). Additionally at 141 DAP, data analysis showed a significant difference between main effects of seeding rates (Fig. 1) and herbicide programs (program #1: >99% and program #2: >97%) on barnyardgrass control. Seeding rate ≥0.5× provided greater barnyardgrass control (>99%) averaged over cultivars.

Barnyardgrass escapes in the POST-only treatment resulted in higher panicle production at harvest (averaged over cultivars and seeding rates) compared to PRE (fb) POST treatment (Fig. 2). Based on ANOVA, rice cultivars did not influence barnyardgrass growth whereas herbicide programs and seeding rates ≥0.5× did, with the greatest control and reduction in panicle production occurring when clomazone was applied PRE. Furthermore, cultivars, seeding rates, and herbicide programs failed to interact for rice yields, and the main effects were nonsignficant.

SIGNIFICANCE OF FINDINGS

Seeding rates of ≤0.25× of the recommended seeding rates can potentially decrease barnyard grass control with herbicides. A well-timed application of clomazone PRE fb imazethapyr and imazamox provides improved control of barnyardgrass over programs that rely solely on imazethapyr and imazamox. Furthermore, the addition of clomazone to herbicide programs in Clearfield rice lessens herbicide selection pressure in the rice crop as well as subsequent crops as a result of reduced barnyardgrass seed production.

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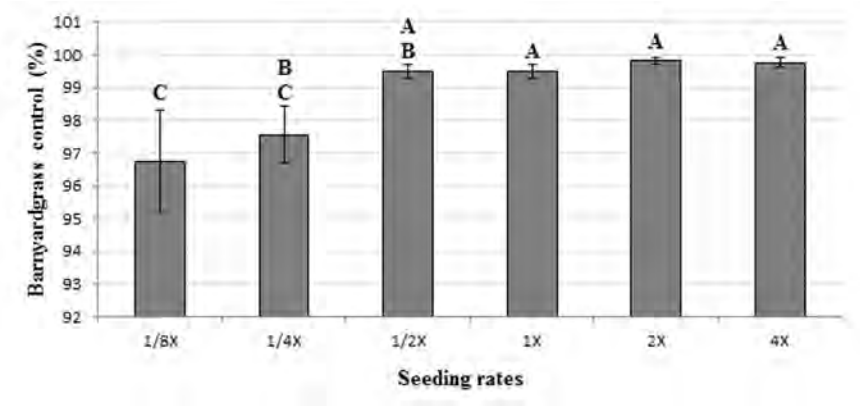

Fig. 1. Barnyardgrass control (%) averaged over cultivars and herbicide programs at 141 days after planting.

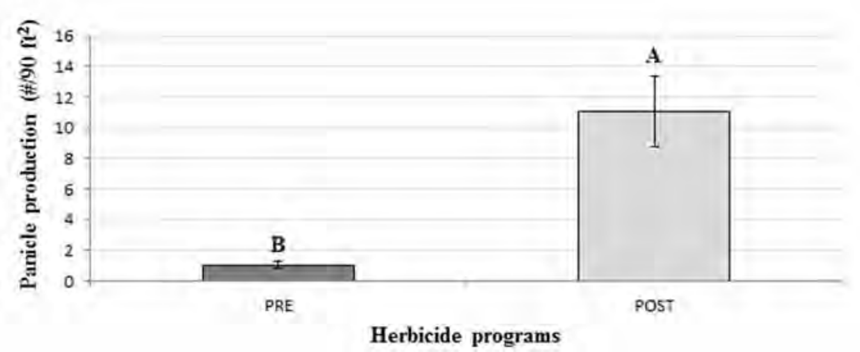

Fig. 2. Barnyardgrass panicle production at rice maturity for two herbicide programs, pre-emergence (PRE) followed by a post-emergence (POST) application compared to a POST application only, averaged over cultivars and seeding rates.

Ammonia Volatilization and Rice Grain Yield as Affected by Simulated Rainfall Amount and Nitrogen Fertilizer Amendment

R.J. Dempsey, N.A. Slaton, T.L. Roberts,
R.J. Norman, R.E. DeLong, and C.G. Massey

ABSTRACT

Urea is the most common nitrogen (N) fertilizer source applied to rice (*Oryza sativa* L.) grown using the direct-seeded, delayed-flood method in Arkansas. Urea is susceptible to ammonia (NH_3) volatilization if not quickly incorporated into the soil by timely rainfall or flooding. Two experiments were conducted in 2013 on an alkaline Calhoun silt loam. Untreated urea (Urea) or N-(n-butyl) thiophosphoric triamide-amended urea (NBPT-Urea) was subjected to six simulated rainfall amounts ranging from 0 to 1 inch. The permanent flood was delayed 6 or 12 days after the application of N and simulated rainfall to enhance the potential for NH_3 volatilization. Ammonia volatilization and grain yield data were regressed on simulated rainfall amount. Cumulative NH_3 volatilization was influenced by a significant N source by simulated rainfall interaction ($P < 0.0001$). Cumulative NH_3 losses ranged from 0.3% to 2.4% for NBPT-Urea and 0.3% to 9.6% for Urea, with the greatest loss when no simulated rainfall was applied. Cumulative NH_3 loss from NBPT-Urea was significantly lower than Urea when simulated rainfall was <0.75 inch, but similar when simulated rainfall amounts were ≥0.75 inch. Rice grain yield was influenced by a significant N source by rainfall interaction ($P = 0.0004$) with differing intercepts due to a trial by N source interaction. For Trial A, yields from rice fertilized with NBPT-Urea were greater than Urea when simulated rainfall was ≥0.3 inch, but Trial B yields between N sources were similar when ≥0.1 inch of simulated rainfall was applied.

INTRODUCTION

Nitrogen is the nutrient applied in the greatest amount to rice grown using the direct-seeded, delayed-flood production method. Urea is the most commonly used N fertilizer due to its high N content (46%), low relative cost, and ease of handling and application. Following urea application to the soil surface, urea undergoes hydrolysis and reacts with the urease enzyme in the soil. Hydrolysis causes a pH increase in the soil adjacent to the fertilizer, which favors the formation of ammonia (NH_3) and can accentuate N loss from surface-applied urea. Practices have been developed to reduce NH_3-N losses including application of urea to a dry soil surface at the 5-lf growth stage, use of an NBPT [N-(n-butyl) thiophosphoric triamide]-containing urease inhibitor, and flooding as quickly as possible (Norman et al., 2013). Prior research with direct-seeded, delayed-flood rice in Arkansas has reported losses from NH_3 volatilization ranging from 20% to 30% (Griggs et al., 2007).

Ten or more days are sometimes required to establish a flood in a field and incorporate the surface-applied urea, during which time rainfall events of various amounts may occur. Rainfall shortly after urea application has been generally considered helpful in reducing NH_3 loss of urea-N since it incorporates the urea into the soil. A minimum of 0.57 inch of rainfall is needed to significantly reduce NH_3 volatilization from surface-applied urea (Holcomb et al., 2011). One often overlooked aspect of applying urea to a dry soil surface, is that the dry soil not only delays urea hydrolysis, but it also slows the nitrification of NH_4-N to NO_3 (Greaves and Carter, 1920). Although rainfall may effectively incorporate urea to prevent or significantly reduce NH_3 loss, the potential for fertilizer-N loss via denitrification to gaseous N following nitrification of the urea-N between a rainfall event and flooding has not been examined. Our research objectives were to compare the effects of simulated rainfall amount and a urease inhibitor on NH_3 volatilization loss of preflood applied-urea and rice grain yield.

PROCEDURES

Site Description

Two field experiments were conducted during the 2013 growing season at the University of Arkansas System Division of Agriculture Pine Tree Research Station near Colt, Ark., on an alkaline Calhoun silt loam (fine-silty, mixed, active, thermic Typic Glossaqualfs) following soybean (*Glycine max* L. Merr.). Selected soil chemical properties for the study areas are presented in Table 1. Phosphorus (60 lb P_2O_5/acre as triple superphosphate) and potassium (75 lb K_2O/acre as muriate of potash) fertilizers were broadcast to each research area and 1 lb EDTA-Zn/acre was applied post-emergence. The long-grain rice cultivar CL152 was drill-seeded into conventionally tilled seedbeds at 90 lb seed/acre on 16 May (Trial A) and 4 June 2013 (Trial B). Rice was drill-seeded into strips that were comprised of nine, 7.5-inch wide rows with a 16.5-inch alley that contained no rice between adjacent strips.

Within each strip of rice, plots with dimensions of 6.0-ft wide by 7.5-ft long were flagged to establish individual plot boundaries for rainfall simulation and N fertilization. The preflood-N treatments included untreated urea (Urea) and NBPT-treated urea (NBPT-Urea; Agrotain Ultra, 0.014 oz NBPT/lb urea; Koch Fertilizer, L.L.C., Wichita, Kan.) at 100 lb N/acre. Each trial also contained two no-N control plots to enable calculation of soil N uptake and urea-N recovery by the difference method. Nitrogen fertilizer was applied at 80% of the N rate predicted to produce maximum (100%) grain yield calculated from the Nitrogen Soil Test for Rice (Roberts et al., 2011). A suboptimal N rate was used to ensure that potential differences in N loss among treatments would result in grain yield differences. Prior to applying the N-fertilizer treatments, a 23.8-sq. inch aluminum ring, the same diameter as the NH_3 volatilization chambers, was placed into the ground and covered to identify the location of the chamber and exclude plot urea-N. After the N treatment was hand-applied to each plot, the chamber cover was removed, a preweighed N amount, equivalent to 100 lb N/acre, of the assigned N source was placed inside the aluminum ring, the simulated rainfall was applied, the ring was removed, and the chamber was installed.

Portable rainfall simulators measuring 6-ft wide × 7.5-ft long were constructed to simulate rainfall. Each simulator was equipped with two Rain Bird® (Rain Bird Corp., Azusa, Calif. and Tucson, Ariz.) SQ Series, full-circle and two Rain Bird® SQ Series, half-circle nozzles positioned 27 inches apart and 29 inches above the ground on a 1-inch PVC frame covered with a removable plastic tarp to reduce water movement due to wind. Water was delivered to the nozzles through 0.5-inch polyethylene tubing (Raindrip, Inc. subsidiary of NDS, Inc., Woodland Hills, Calif.) which was connected to a 25-gal tank (County Line® Deluxe Spot Sprayer, Green Leaf, Inc., Fontanet, Ind.). The water used for rainfall simulation was groundwater obtained from the station's spray pad water hose.

At the 4-lf stage, Urea and NBPT-Urea were applied to a dry soil surface at 8:00 AM on 12 and 25 June 2013 for Trials A and B, respectively. Nitrogen sources were subjected to simulated rainfall amounts of 0, 0.125, 0.25, 0.5, 0.75, or 1.0 inch and applied between 5 to 11 h (e.g., start to finish) after the preflood urea-N was applied. A permanent flood was established 12 (Trial A) and 6 d (Trial B) after urea-N and simulated rainfall application.

MATERIALS AND METHODS

Early-season NH_3 volatilization as affected by simulated rainfall amount and N source was evaluated only in Trial A using the semi-closed chamber method (Griggs et al., 2007; Massey et al., 2011). Volatilization chambers consisted of clear acrylic tubes 5.5-inch inner diameter × 24-inch tall that were driven 4 inches into the soil to prevent air exchange at the soil surface. Volatilized N was trapped by polyurethane foam sorbers (5.5-inch diameter × 1-inch height) saturated with 0.7 fl. oz. of 0.73 M H_3PO_4-33% glycerin (v:v). Each acrylic chamber contained two foam sorbers, which were installed immediately after the chamber was driven into the soil. The first sorber was positioned 6 inches below the top of the chamber to trap NH_3 from the applied fertilizer and the second sorber was level with the top of the chamber to absorb atmospheric NH_3. Sorbers were changed 2, 3, 5, 8, and 11 days after N-fertilizer application and simulated rainfall. At each sample date, the innermost sorber was removed, placed in a sealed plastic bag, and replaced immediately. The same topmost sorber was used for the entire trial. Removed sorbers were extracted by adding 3.4 fl oz of 2 *M* KCl solution and allowing saturation of the sorber overnight. Each saturated sorber was hand-squeezed to extract a 1.7-fl oz aliquot that was used to determine NH_4-N concentration by colorimetery (SKALAR auto-analyzer, San + Segmented Flow, Norcross, Ga.; Mulvaney, 1996).

At the initiation of the study, outdoor temperature/humidity dataloggers (HOBO Pro v2-Part No. U23-001, Onset Computer Corp. Inc., Proccasett, Mass.) were suspended 0.5 inch above the soil surface inside and outside the semi-closed chamber in the no-N plots in each block ($n = 4$) to measure air temperature and humidity, since these environmental parameters are known to influence NH_3 loss (Vaio et al., 2008; Rogers et al., 2013). The dataloggers recorded temperature and humidity data every 30 min. To reduce the chance of inaccurate temperature and humidity measurements, and limit debris from entering the chamber, each chamber was wrapped in a white trash bag and a white 5-gal bucket was suspended on a 0.25-inch PVC frame over the top of each chamber. The critical relative humidity (CRH) of urea [the relative humidity (RH) where urea can dissolve] was calculated from temperature data (°C) using the equation described by Vaio et al. (2008):

$$\text{CRH (\%)} = 84.669 - 0.1457T - 0.0055T^2$$

where T is temperature (°C).

Dry matter accumulation and total N uptake were measured, but will not be discussed in this article. Dry matter and total N uptake were obtained by taking a 3-ft linear section of whole, above-ground rice plants at 5% to 10% heading. At maturity, a 38-ft^2 section from the center of 8 rows of each plot was harvested for grain yield using a small-plot combine. Immediately after harvest, grain weight and moisture were determined for each plot. The reported grain yields were adjusted to a uniform moisture content of 12% for statistical analysis.

The experiment was a split-plot design with trial being the main plot and the 2 (N source) × 6 (rainfall amount) factorial treatment structure served as the subplot. Replicate NH_3 volatilization and grain yield data were regressed on simulated rainfall amount, allowing for linear and quadratic terms with coefficients depending on trial and N source. The most complex nonsignificant ($P > 0.15$) model terms were removed sequentially and the model was refit until a satisfactory model was obtained. Comparisons between N sources were evaluated at $P = 0.10$ when necessary. Statistical analysis was performed using the Mixed procedure in SAS v. 9.3 (SAS Institute Inc., Cary, N.C.).

RESULTS AND DISCUSSION

Ammonia Volatilization

Ammonia volatilization was measured using the semi-closed chamber method during the 11 day experiment and cumulative NH_3 loss was regressed on simulated rainfall amount (Fig. 1). Cumulative NH_3 volatilization was influenced by a significant N source by rainfall interaction ($P < 0.0001$). Cumulative NH_3 loss from both N sources decreased nonlinearly (quadratic) as simulated rainfall amount increased. After 11 days, the cumulative NH_3 losses ranged from 0.3% to 2.4% for NBPT-Urea and 0.3% to 9.6% for Urea with the greatest loss occurring from urea with no simulated rainfall. NBPT-Urea significantly reduced (e.g., not different than 0) cumulative NH_3 loss when simulated rainfall amounts were >0.3 inch, but Urea required >0.8 inch of simulated rainfall to significantly reduce cumulative NH_3 volatilization. The 0.8 inch of rainfall needed to effectively incorporate urea and prevent NH_3 loss on the Calhoun silt loam is greater than the 0.57 inch of simulated rainfall reported by Holcomb et al. (2011) to incorporate urea and prevent NH_3 loss on a Adkins fine sandy loam (coarse-loamy, mixed, superactive, mesic Xeric Haplocalcids). Cumulative NH_3 loss from NBPT-Urea was significantly lower than Urea when simulated rainfall was <0.75 inch, but similar when simulated rainfall amounts were ≥0.75 inch.

Rice Grain Yield

Rice grain yield was a linear function of simulated rainfall amount, the linear slope depended on N source and simulated rainfall amount, and the intercept differed among N sources and trials ($P = 0.0004$, Fig. 2). The yields of rice fertilized with NBPT-Urea ranged from 181 to 188 bu/acre in Trial A and 159 to 177 bu/acre in Trial B and, within each trial, were statistically similar across simulated-rainfall amounts resulting in a common slope value that was not different than zero ($P = 0.7409$). The yields of rice receiving Urea ranged from 161 to 184 bu/acre in Trial A and 155 to 176 bu/acre in Trial B and decreased linearly (slope, -17.65 bu/acre/in simulated rainfall) as simulated rainfall amount increased. For Trial A, grain yields from rice fertilized with NBPT-Urea were greater than Urea when simulated rainfall was ≥0.3 inch, but for Trial B yields between N sources were similar when simulated rainfall was >0.1 inch.

SIGNIFICANCE OF FINDINGS

Based on the measured in-field NH_3 volatilization losses, rice grain yields were expected to increase as rainfall amounts increased due to urea-N being incorporated into the soil. However, our results suggest that NH_3 volatilization and denitrification may interact to influence cumulative N loss when rainfall occurs between urea application and the establishment of the permanent flood. The use of NBPT significantly reduced NH_3 losses as measured in the semi-closed chambers and may have effectively delayed nitrification prior to the establishment of the permanent flood. Grain yield behavior was not associated with NH_3 volatilization loss as measured in the semi-closed chambers, indicating another N-loss pathway played an important role in rice uptake of the preflood-N or, alternatively, N loss in the chamber was not representative of what happened in the field. The RH within the chamber was constantly above the CRH, while outside the chamber RH fluctuated above and below the CRH. The potential for NBPT to delay nitrification (e.g., via delayed urea hydrolysis), albeit by only a few days, may also reduce nitrification and subsequent N loss attributed to denitrification following flood establishment. Additional research is required to better understand the processes that occur across a range of rainfall amounts and frequencies between the time of urea-N application and establishing the permanent flood.

ACKNOWLEDGMENTS

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Table 1. Selected chemical property means (n = 2) of a Calhoun silt loam sampled (4 inches) prior to planting for Trial A and B.

Trial	Soil pH	Mehlich-3 extractable nutrients								Total C	Total N
		P	K	Ca	Mg	S	Mn	Cu	Zn		
	(1:2)	------------------------------- (ppm)							-------------------------------	----- (%) ----	
A	7.4	18	88	1,583	332	8.1	293	1.0	1.4	1.03	0.09
B	7.6	26	85	2,040	330	10.6	339	1.2	1.6	1.08	0.09

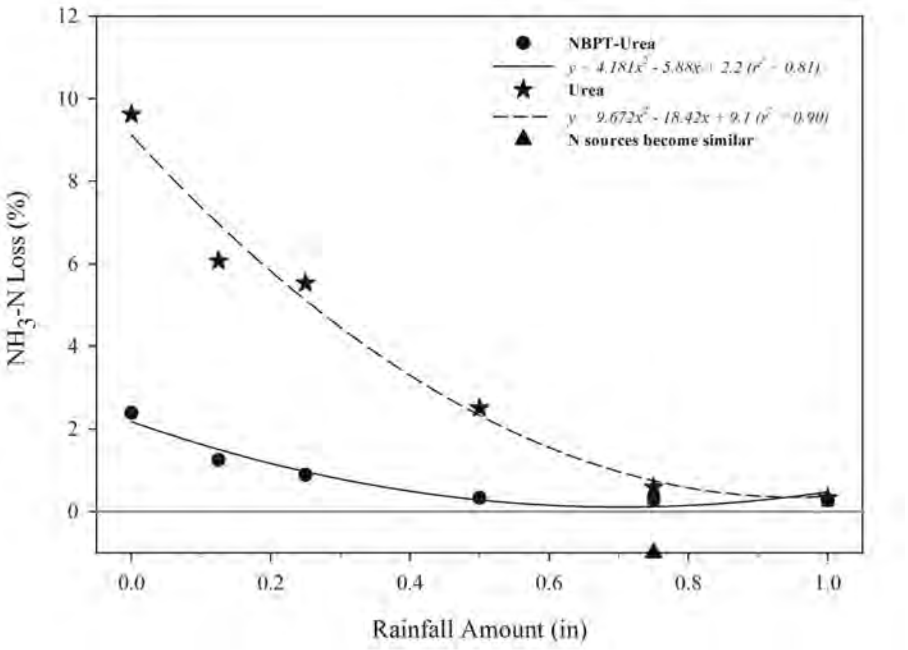

Fig. 1. Cumulative N loss as influenced by the interaction of N source and simulated rainfall amount for Trials A and B.

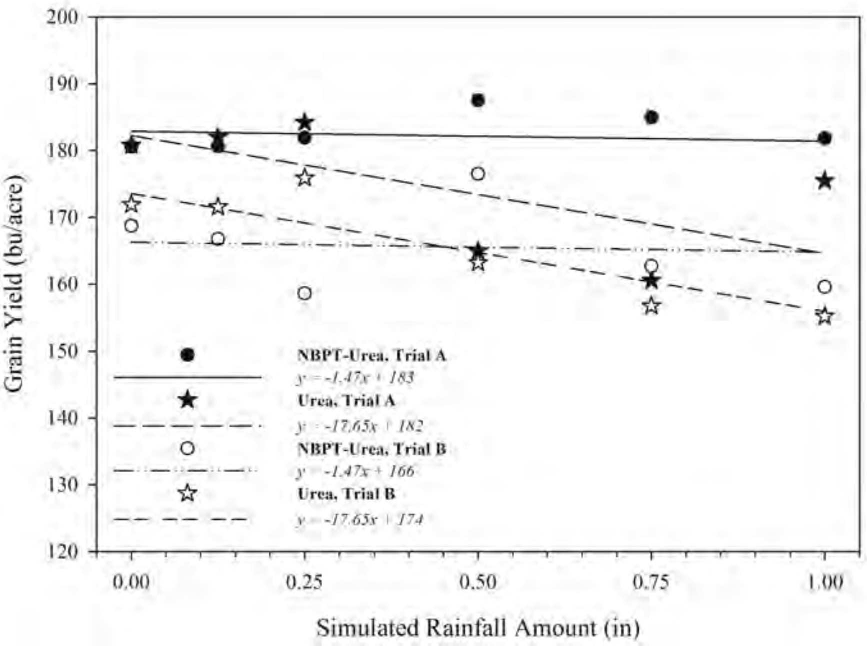

Fig. 2. Rice grain yield as influenced by the interaction of trial, N source, and simulated rainfall amount for Trials A and B.

Rice Grain Yield as Affected by Simulated Rainfall Timing and Nitrogen Fertilizer Amendment

R.J., Dempsey, N.A. Slaton, T.L. Roberts,
R.J. Norman, R.E. DeLong, and C.G. Massey

ABSTRACT

Urea is recommended to be applied to a dry soil surface and incorporated quickly by flood establishment to reduce ammonia (NH_3) volatilization in the direct-seeded, delayed-flood method of rice (*Oryza sativa* L.) production. Two trials were established in 2013 on an alkaline Calhoun silt loam to evaluate rice grain yield as affected by five nitrogen (N) sources [untreated urea (Urea), N-(n-butyl) thiophosphoric triamide (NBPT)-amended urea (UI-Urea), Nitrapyrin-amended urea (NI-Urea), and NBPT+Nitrapyrin-amended urea (UNI-Urea)] and three simulated rainfall timings [no simulated rainfall (NOR), simulated rainfall applied before N application (RBN), and simulated rainfall applied after N application (RAN)]. Rice grain yield was influenced by the main effects of N source and simulated rainfall timing. Averaged across trials and simulated rainfall times, rice yields fertilized with the various N sources followed the trend of UI-Urea (162 bu/acre) = UNI-Urea (160 bu/acre) > Urea (147 bu/acre) = NI-Urea (147 bu/acre). Rice yield was greatest when no simulated rainfall was applied (159 bu/acre), intermediate for RAN (154 bu/acre), and lowest for RBN (149 bu/acre). Under the conditions of these trials, applying urea-N to a dry soil surface and use of NBPT, regardless of soil condition, resulted in the greatest rice grain yields.

INTRODUCTION

Urea is the nitrogen (N) fertilizer most commonly used to fertilize flood-irrigated rice because of its high N analysis (46% N), low cost relative to other N-containing fertilizers, and lack of NO_3-N. Despite these favorable characteristics, urea is also the granular N fertilizer that is most prone to NH_3 volatilization. Prior research with direct-seeded, delayed-flood rice in Arkansas has reported NH_3 volatilization losses ranging from 20% to 30% (Griggs et al., 2007). In order to minimize NH_3 loss, recommendations are to apply urea to a dry soil surface at the 4- to 5-lf stage, incorporate the urea-N into the soil, and stop nitrification by establishment of a permanent flood as quickly as possible, and use of an N-(n-butyl) thiophosphoric triamide (NBPT)-containing urease inhibitor (Norman et al., 2013). In some years, rainfall occurs frequently at the time rice is ready for N fertilization and prevents the application of urea to a dry soil surface. Ernst and Massey (1960) showed that 38% of urea-N can be lost via NH_3 volatilization when applied to a soil with 20% (w/w) soil moisture, but can decrease to 21% when applied to a soil with 10% (w/w) soil moisture.

After urea-N is applied, 10 days or more may be needed to establish the permanent flood. Rainfall before or after urea application can influence NH_3 volatilization N loss and N loss caused by nitrification before the flood is established and denitrification after the flood. Golden et al. (2009) showed that nitrification of urea-N was complete in as few as 10 days on an alkaline Calhoun silt loam incubated at 25 °C and a moisture content of 25% (w/w). The use of a nitrification inhibitor [i.e. Nitrapyrin (2-chloro-6-(trichloromethyl)-pyridine)] can be useful in slowing the rate of nitrification in flood-irrigated rice (Wells, 1977; Sharma and Prasad, 1980; Watanabe, 2006) and can possibly be a useful tool for reducing N-loss via denitrification. The potential for fertilizer-N loss via denitrification following nitrification of the urea-N between rainfall and flooding has not been examined. Our research objectives were to compare the effects of simulated rainfall timing and urease and nitrification inhibitor amendments applied to preflood urea-N on rice grain yield.

PROCEDURES

Site Description

Two field experiments were conducted during the 2013 growing season at the University of Arkansas System Division of Agriculture Pine Tree Research Station near Colt, Ark., on a Calhoun silt loam (fine-silty, mixed, active, thermic Typic Glossaqualfs) following soybean (*Glycine max* L. Merr.). Selected soil chemical properties for the study areas are presented in Table 1. Phosphorus (60 lb P_2O_5/acre as triple superphosphate) and potassium (75 lb K_2O/acre as muriate of potash) fertilizers were broadcast to each research area and 1 lb EDTA-Zn/acre was applied post-emergence. The long-grain rice cultivar CL152 was drill-seeded into conventionally tilled seedbeds at 90 lb seed/acre on 17 April (Trial A) and 16 May 2013 (Trial B). Rice was drill-seeded into strips that were comprised of nine, 7.5-inch wide rows with a 16.5-inch alley that contained no rice between adjacent strips.

Within each strip of rice, 6.0-ft wide by 7.5-ft long plots were flagged to establish individual plot boundaries for rainfall simulation and N fertilization. The preflood-N treatments included untreated urea (Urea), N-(n-butyl) thiophosphoric triamide (NBPT)-treated urea (UI-Urea; Agrotain® Ultra, 0.014 oz NBPT/lb urea; Koch Fertilizer, L.L.C., Wichita, Kan.), Nitrapyrin-treated urea (NI-Urea; Instinct, 0.390 oz Nitrapyrin/lb urea;

Dow Agrosciences, Indianapolis, Ind.), and NBPT+Nitrapyrin-treated urea (UNI-Urea) with each source applied at 100 lb N/acre. Each trial also contained two no-N control plots to enable calculation of soil N uptake and urea-N recovery by the difference method. Nitrogen fertilizer was applied at 80% of the N rate predicted to produce maximum (100%) grain yield calculated from the Nitrogen Soil Test for Rice (Roberts et al., 2011). A suboptimal-N rate was used to ensure that potential differences in N loss among treatments would result in grain yield differences.

Portable rainfall simulators (6.0-ft wide × 7.5-ft long) were constructed to simulate rainfall. Each simulator was equipped with two Rain Bird® (Rain Bird Corp., Azusa, Calif. and Tucson, Ariz.) SQ Series, full-circle and two Rain Bird® SQ Series, half-circle nozzles positioned 27 inches apart and 29 inches above the ground on a 1-inch PVC frame with the sides covered with a removable plastic tarp to reduce water movement due to wind. Water was delivered to the nozzles through 0.5-inch polyethylene tubing (Raindrip, Inc. subsidiary of NDS, Inc., Woodland Hills, Calif.), which was connected to a 25-gal tank (County Line® Deluxe Spot Sprayer, Green Leaf, Inc., Fontanet, Ind.). The water used for rainfall simulation was groundwater obtained from the station's spray pad area.

At the 4-lf stage, N sources were applied at 7:00 PM on 28 May (Trial A) and 8:00 AM on 11 June 2013 (Trial B). The desired amount of simulated rainfall was 0.5 inch, but for Trial B the amount applied was 0.3 inch due to a recent rainfall event. Each N source was subjected to three simulated rainfall timings of: i) no simulated rainfall (NOR), ii) simulated rainfall applied before N application (RBN), or iii) simulated rainfall applied after N application (RAN). Simulated rainfall was applied 4 (Trial A) and 18 h (Trial B) before N application and 14 (Trial A) and 5 h (Trial B) after N application. The permanent flood was established 8 (Trial A) and 13 days (Trial B) after simulated rainfall and N application to allow time for NH_3 volatilization and nitrification to occur.

Dry matter accumulation and total aboveground-N uptake were measured, but will not be discussed. Dry matter was measured by taking a 3-ft linear section of whole, aboveground rice plants at 10% heading. At maturity, a 38-ft^2 section from the center of 8 rows of each plot was harvested for grain yield using a small-plot combine. Immediately after harvest, grain weight and moisture were determined for each plot. The reported grain yields were adjusted to a uniform moisture content of 12% for statistical analysis.

The experiment was a randomized complete block design with a 4 (N source) × 3 (simulated rainfall timing) factorial treatment structure and four blocks. Statistical analysis was performed using the MIXED procedure in SAS v. 9.3 (SAS Institute Inc., Cary, N.C.). Analysis of variance and mean separations were conducted, where appropriate, using Fisher's Protected Least Significant Difference (LSD) test at $P = 0.10$.

RESULTS AND DISCUSSION

Rice Grain Yield

A significant rainfall event occurred 3 (1.3 inches, Trial A) or 6 days (3.5 inches, Trial B) after N application and simulated rainfall. This significant amount of rainfall possibly incorporated all the urea-N and accelerated the nitrification rate and increased denitrification for all treatments. Rice grain yield was influenced by the main effects of N source (*P* = 0.0010, Table 2) and simulated-rainfall timing (*P* = 0.0379, Table 3), but not their interaction (*P* = 0.4364). Rice fertilized with UI-Urea produced the greatest yield compared to the other N sources, but was not significantly different than rice fertilized with UNI-Urea (Table 2). Rice fertilized with Urea and NI-Urea produced similar yields that were 8% to 9% lower than UI-Urea and UNI-Urea, suggesting that the urease inhibitor, but not the nitrification inhibitor, reduced urea-N loss.

The effect of simulated-rainfall timing, averaged across trials and N sources, showed the greatest grain yield was produced by rice that received NOR and was about 7% greater than rice receiving RBN (Table 3). Rice that received RAN produced an intermediate yield that was not different from the yields produced by rice receiving the NOR or RBN treatments. This could be due to reduced N-loss via NH_3 volatilization by urea-N being incorporated into the soil, but amplified N-loss via denitrification due to increased nitrification. The mean yield differences among the three simulated rainfall timings indicate that the amount of N lost in these trials was relatively small. We anticipated that the RAN treatment would reduce NH_3 loss but might stimulate nitrification of the added urea-N and result in denitrification loss after the flood was established.

SIGNIFICANCE OF FINDINGS

Under the conditions of the two trials, results showed that applying urea-N to a dry soil surface or using an NBPT-containing urease inhibitor, regardless of soil conditions, will result in the greatest rice yield. Previous research reports that about 0.5 inch of rainfall is needed to effectively incorporate urea-N (Holcomb et al., 2011) on a fine sandy loam, but our experiment suggests that a greater amount of rainfall is needed for a Calhoun silt loam or the added moisture accelerates nitrification and accentuates denitrification after the establishment of the flood. The NI-Urea treatment was not different than Urea, indicating that the nitrification inhibitor did not slow the reaction of NH_4-N to NO_3-N. However, UI-Urea may have the potential of briefly delaying nitrification (e.g., via delaying urea hydrolysis), and therefore reducing the N loss attributed to denitrification. Grain yields indicate that there is not a synergistic effect in combining NBPT and Nitrapyrin. Additional research is needed to understand how NBPT affects the short-term nitrification rate of urea-N between time of N application and the establishment of the permanent flood.

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Table 1. Selected chemical property means (n = 2) of a Calhoun silt loam sampled (4 inches) prior to planting for Trials A and B.

	Soil	Mehlich-3 extractable nutrients								Total	Total
Trial	pH	P	K	Ca	Mg	S	Mn	Cu	Zn	C	N
	(1:2)	------------------------------- (ppm) -------------------------------								----- (%) ----	
A	7.3	18	88	1,579	340	9	289	1.1	1.9	0.96	0.09
B	7.6	20	86	2,065	338	12	337	1.1	1.6	1.08	0.10

Table 2. Effect of nitrogen (N) source, averaged across trials and simulated rainfall timings, on rice grain yield in 2013.

N source[†]	Rice grain yield
	(bu/acre)
No-N	101[‡]
UI-Urea	162 a[§]
UNI-Urea	160 a
Urea	147 b
NI-Urea	147 b
LSD (0.10)	7

[†] Abbreviations: no application of N (No-N), untreated urea (Urea), N-(n-butyl) thiophosphoric triamide-treated urea (UI-Urea), Nitrapyrin-treated urea (NI-Urea), NBPT and Nitrapyrin-treated urea (UNI-Urea).

[‡] No-N treatment was not used in the analysis but represents the effect of N application.

[§] Means followed by the same letter indicated no statistical difference at P = 0.10.

Table 3. Effect of simulated rainfall timing, averaged across trials and N sources, on rice grain yield.

Simulated rainfall timing	Rice grain yield
	(bu/acre)
No water applied	159 a[†]
Simulated rainfall applied after N application	154 ab
Simulated rainfall applied before N application	149 b
LSD (0.10)	6

[†] Means followed by the same letter indicated no statistical difference at P = 0.10.

RICE CULTURE

Development of the Arkansas Degree-Day 50 Thermal Unit Thresholds for New Rice Cultivars

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ABSTRACT

The Degree-Day 50 (DD50) computer program has been one of the most successful programs developed by the University of Arkansas System Division of Agriculture. The program utilizes thermal units accumulated during the growing season to calculate predicted dates rice will reach growth stages critical to optimal crop management. However, the computer program must be continually updated as new conventional and hybrid rice cultivars are released. To accomplish this objective, DD50 thermal unit thresholds must be established in a controlled research environment. The DD50 thermal unit accumulations and grain yield performance of each new rice cultivar were evaluated over four seeding dates during 2013 in the dry-seeded, delayed-flood management system that is most commonly used in the southern United States. Rice cultivars evaluated in 2013 included: Antonio, Caffey, CL152, CL162, Colorado, Della-2, Jazzman-2, Jupiter, LaKast, Mermentau, Roy J, Wells, and the hybrid RiceTec XL753. Grain and milling yields were measured at maturity to evaluate the influence of seeding date on grain and milling yield potential.

INTRODUCTION

The Degree-Day 50 (DD50) computer program was developed in 1978 by the University of Arkansas System Division of Agriculture for use as a crop management tool for rice. The program has been expanded over time to predict at least 26 key management decisions including nitrogen (N) fertilizer timing, permanent flood establishment, timing of pesticide applications, reminders for disease scouting, and suggested harvest timing. Each DD50 file generated is field- and cultivar-specific for the current growing season. The program utilizes cultivar-specific data to predict rice plant development based on the accumulation of DD50 thermal units from the date of seedling emergence. Thermal units are calculated from 30-year average weather data which has been collected from the National Weather Service weather station closest to a rice producer's location in Arkansas. The cultivar-specific data are acquired from annual studies of promising experimental lines and all newly released conventional and hybrid rice cultivars. Rice cultivars are planted at four seeding dates across the recommended range of rice seeding dates for Arkansas. Threshold DD50 thermal unit data from these studies are used in the DD50 computerized rice management program to enable predictions of dates when important plant development stages will occur, which assists growers and consultants in accurately timing specific management practices. Therefore, the objectives of this study were to develop a database for promising new rice cultivars, to verify the database for existing cultivars, and to assess the effect of seeding date on DD50 thermal unit accumulations. In addition to these objectives, the influence of seeding date on a cultivar's grain and milling yield performance was considered to determine optimal seeding date for new cultivars.

PROCEDURES

The study was conducted during 2013 at the University of Arkansas System Division of Agriculture Rice Research and Extension Center (RREC) near Stuttgart, Ark., on a DeWitt silt loam soil. Twelve conventional rice cultivars (Antonio, Caffey, CL152, CL162, Colorado, Della-2, Jazzman-2, Jupiter, LaKast, Mermentau, Roy J, and Wells) were drill-seeded at a rate of 40 seed/ft^2 in plots 9 rows (7-inch spacing) wide and 16 ft in length. The hybrid rice cultivar RiceTec XL753 was sown into the same plot configuration using the recommended reduced seeding rate for hybrids of 14 seed/ft^2. General seeding, seedling emergence, and flood dates are shown in Table 1. The seeding dates in 2013 were 28 March, 16 April, 30 May, and 17 June. Normal cultural practices for dry-seeded, delayed-flood rice production were followed. All plots received 120 lb N/acre as a single preflood application of urea at the 4- to 5-lf growth stage. The permanent flood was applied within 2 days of preflood N fertilization and maintained until rice reached maturity. Data collected included: maximum and minimum daily temperatures, date of seedling emergence, and the number of days and DD50 thermal units required to reach 0.5-inch internode elongation (IE) and 50% heading. 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 and percent total white rice (HR/TR). Each seeding date was arranged in a randomized complete block design with four replications. Statistical analyses were conducted using PROC GLM SAS v. 9.2 (SAS Institute, Inc., Cary, N.C.) and mean separations were conducted based upon Fisher's Protected Least Significant Difference test ($P = 0.05$) where appropriate.

RESULTS AND DISCUSSION

The time between seeding and emergence ranged from 8 to 20 days during 2013 (Table 1). During the period between seeding and emergence, thermal unit accumulations were very similar among the three earliest seeding dates and much greater in the 17 June seeding date (data not shown). Generally in seeding date studies, the days between seeding and emergence decreases as seeding date is delayed. In this study year, days from seeding to emergence decreased as seeding date was delayed from March until late May, and then increased in the June seeding date (Table 1). This delay in emergence of the 17 June seeding date may be due to lack of rainfall and the need to flush to promote stand establishment. The time between seeding and flooding also followed this same pattern, ranging from 64 days for the March seeding date to 34 days for the May seeding date and increasing to 39 days for the June seeding date. During 2013, time from emergence to flooding was 44 days for the March seeding date, 36 days for the April seeding date, and decreased to 26 and 28 days for the May and June seeding dates, respectively.

The time required from emergence to 0.5-inch IE averaged 56 days across all cultivars and seeding dates (Table 2). When averaged across cultivars, time to reach 0.5-inch IE ranged from 70 days when seeded in late March to 46 days when seeded in mid-June. The number of days required by each cultivar to reach 0.5-inch IE also decreased as seeding date was delayed from March to late May, but was similar between the May and June seeding dates. During 2013, time of vegetative growth, averaged across seeding dates, ranged from 52 days for Colorado to 62 days for Jupiter. The DD50 thermal unit accumulations during vegetative growth ranged from a low of 1331 for Colorado and Mermentau to a high of 1614 for Jupiter when averaged across seeding dates.

The time required for plant development between emergence and 50% heading averaged 86 days across all cultivars and seeding dates during 2013 (Table 3). Average time for cultivars in each seeding date to reach 50% heading ranged from 100 days when seeded in late March to 77 days when seeded in mid-June. Average time for individual cultivars to reach 50% heading ranged from 82 days for Colorado to 93 days for Roy J. Thermal unit accumulation between emergence and 50% heading averaged 2323 units during 2013. For individual cultivars, average DD50 thermal unit accumulation ranged from a low of 2194 for Colorado to a high of 2520 for Roy J, and was generally highest for all cultivars in the 16 April seeding date.

During 2013, average grain yield for the study was 173 bu/acre (Table 4). Grain yield, averaged across cultivars, was around 200 bu/acre for the 28 March and 16 April seeding date and decreased to 161 and 136 bu/acre for the 30 May and 17 June seeding dates, respectively. The hybrid RT XL753 had by far the highest yield of all the cultivars and maintained yields over 200 bu/acre when seeded up to late May and then only decreased to 182 bu/acre when seeded 17 June. RoyJ produced yields of 200 bu/acre or for the 28 March and 16 April seeding dates and then only decreased to 191 bu/acre when seeded 30 May. None of the conventional cultivars yielded 150 bu/acre or more when seeded 17 June, although Jupiter was close.

During 2013, across seeding dates and cultivars, grain milling yield averaged 62% head rice and 67% total rice (Table 5). Average percent total rice was similar among the four seeding dates. Average percent head rice was lowest in the earliest seeding date and similar among the three later seeding dates. All cultivars averaged 60% or greater head rice yields during this study year; however, the long-grain cultivars CL152 and Mermentau each maintained head rice yields of greater than 60% across all seeding dates during 2013.

SIGNIFICANCE OF FINDINGS

The data from 2013 will be used to refine the DD50 thermal unit thresholds for new cultivars and hybrids being grown. The grain and milling yield data will contribute to the database of information used by University personnel to help producers make decisions regarding rice cultivar selection, particularly for early and late seeding situations.

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Table 1. General seeding, seedling emergence, and flooding date information for the Degree-Day 50 seeding date study in 2013 at the Rice Research and Extension Center near Stuttgart, Ark.

	Seeding date			
	28 March	16 April	30 May	17 June
Emergence date	17 April	30 April	7 June	28 June
Flood date	31 May	5 June	3 July	26 July
Days from seeding to emergence	20	14	8	11
Days from seeding to flooding	64	50	34	39
Days from emergence to flooding	44	36	26	28

Table 2. Influence of seeding date on Degree-Day 50 accumulations and days from emergence to 0.5-inch internode elongation of selected rice cultivars in studies conducted at the Rice Research and Extension Center during 2013.

	Seeding date									
	28 March		16 April		30 May		17 June		Average	
Cultivar	days	DD50 units	days	DD50 units	days	DD50 units	days	DD50 units	days	DD50 units
Antonio	67	1401	56	1462	46	1356	42	1230	53	1362
Caffey	74	1617	65	1722	52	1514	51	1468	61	1580
CL152	70	1493	58	1524	49	1437	46	1358	56	1453
CL162	69	1462	58	1524	45	1326	43	1262	54	1393
Colorado	66	1370	55	1431	44	1295	42	1230	52	1331
Della-2	70	1493	59	1556	49	1437	48	1404	57	1472
Jazzman-2	70	1493	56	1462	46	1356	44	1294	54	1401
Jupiter	76	1667	66	1750	54	1573	51	1468	62	1614
LaKast	72	1556	60	1588	49	1437	49	1424	58	1501
Mermentau	67	1401	54	1401	45	1326	41	1198	52	1331
Roy J	77	1691	64	1691	52	1514	51	1468	61	1591
RT XL753	68	1431	56	1462	45	1326	42	1230	53	1362
Wells	73	1588	61	1617	52	1514	52	1492	60	1553
Mean	70	1504	59	1551	48	1410	46	1488	56	1447
C.V.	2.81	3.93	2.45	3.50	2.42	2.35	3.95	4.11	18.34	6.82
LSD (0.05)	2.8	84.0	2.1	77.1	1.7	47.1	2.6	78.5	NS[a]	68.8

[a] NS = not significant.

Table 3. Influence of seeding date on Degree-Day 50 accumulations and days from emergence to 50% heading of selected rice cultivars in studies conducted at the Rice Research and Extension Center during 2013.

	Seeding date									
	28 March		16 April		30 May		17 June		Average	
Cultivar	days	DD50 units	days	DD50 units	days	DD50 units	days	DD50 units	days	DD50 units
Antonio	97	2291	87	2372	78	2255	75	2186	84	2276
Caffey	97	2291	91	2479	78	2255	75	2186	85	2303
CL152	103	2449	89	2422	83	2407	80	2323	89	2400
CL162	98	2319	86	2346	78	2255	73	2122	84	2260
Colorado	95	2230	85	2319	75	2169	71	2058	82	2194
Della-2	103	2449	91	2479	82	2375	80	2323	89	2406
Jazzman-2	97	2291	86	2346	79	2284	76	2217	85	2284
Jupiter	99	2346	91	2479	78	2255	75	2186	86	2316
LaKast	98	2319	86	2346	78	2255	76	2217	85	2284
Mermentau	100	2372	88	2396	79	2284	77	2249	86	2325
Roy J	107	2569	95	2598	85	2470	84	2443	93	2520
RT XL753	96	2261	86	2346	75	2169	75	2186	83	2240
Wells	102	2422	89	2422	82	2375	81	2351	89	2392
Mean	100	2366	89	2426	79	2292	77	2361	86	2323
C.V.	1.64	1.94	1.26	1.70	1.39	1.45	1.59	1.63	11.29	4.08
LSD (*P* = 0.05)	2.3	65.3	1.6	58.8	1.6	47.5	1.7	51.8	NS[a]	66.1

[a] NS = not significant.

Table 4. Influence of seeding date on grain yield of selected rice cultivars in studies conducted at the Rice Research and Extension Center during 2013.

	Grain yield by planting date				
Cultivar	28 March	16 April	30 May	17 June	Average
	(bu/acre)				
Antonio	194	198	167	138	174
Caffey	217	223	170	133	186
CL152	197	195	136	118	161
CL162	162	175	128	116	145
Colorado	158	165	139	131	148
Della-2	173	171	138	114	149
Jazzman-2	177	176	113	138	151
Jupiter	218	225	179	148	193
LaKast	212	231	177	138	189
Mermentau	215	215	161	129	180
Roy J	205	200	191	125	180
RT XL753	237	238	209	182	216
Wells	186	204	177	131	174
Mean	198	203	161	136	173
C.V.	6.80	4.80	7.94	5.90	18.41
LSD (P = 0.05)	19.4	14.3	18.4	11.5	22.24

Table 5. Influence of seeding date on milling yield of selected rice cultivars in studies conducted at the Rice Research and Extension Center during 2013.

	Milling yield[a] by planting date				
Cultivar	28 March	16 April	30 May	17 June	Average
	(%HR - %TR)				
Antonio	60-68	63-69	64-68	64-68	63-68
Caffey	58-67	62-67	64-67	61-65	61-67
CL152	63-69	65-69	66-68	63-67	64-68
CL162	56-67	62-68	63-67	61-66	61-67
Colorado	58-67	59-67	62-67	63-67	61-67
Della-2	60-66	63-67	64-67	62-66	62-67
Jazzman-2	60-68	64-68	63-66	65-68	63-68
Jupiter	61-65	63-67	64-66	60-63	62-65
LaKast	57-67	60-69	64-68	63-67	61-68
Mermentau	62-67	63-68	63-67	62-66	63-67
Roy J	60-68	62-69	62-67	60-66	61-68
RT XL753	57-68	58-69	63-69	61-67	60-68
Wells	55-68	61-70	65-69	60-66	60-68
Mean	59-67	62-68	64-67	62-66	62-67

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

Utilization of On-Farm Testing to Evaluate Rice Cultivars

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ABSTRACT

On-farm testing provides researchers with the best opportunity to evaluate the performance of cultivars under production conditions. By placing trials throughout the state under production management conditions, more accurate performance evaluations can be made for grain yield, milling quality, and profit. These trials also provide a more accurate representation of cultivar performance across environmental conditions and soil types which influence fertility, weed, disease, and insect management practices. Proper cultivar selection for a particular field can reduce production costs and increase profits for the grower by minimizing problems associated with cultivars less suited to a particular growing situation. Therefore, performance evaluations accounting for the range of previously listed factors across many environments are important to overall cultivar selection. Initiated in 2013, the Producer Rice Evaluation Program (PREP) utilizes studies in production fields consisting of commercial cultivars and experimental lines to evaluate, disease, lodging, grain yield potential, and milling quality under various environmental and cultural management conditions found in Arkansas.

INTRODUCTION

The goal of the University of Arkansas System Division of Agriculture is to have a complete production package available 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. Many factors can influence grain yield potential including: seeding date, soil fertility, water quality and management, disease pressure, weather events, and cultural management practices.

Rice diseases are an important constraint to profitable rice production in Arkansas. To reduce disease potential, we recommend the use of host-plant resistance, optimum cultural practices, and fungicides (only when necessary) based on integrated pest management (IPM) practices for disease control. The use of resistant cultivars, combined with optimum cultural practices, provide growers with the opportunity to maximize profit at the lowest disease control expenditure 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 is not complete for many of the environments where rice is grown in Arkansas because diseases or other problems may not be observed in nurseries conducted on experiment stations. With some knowledge of field history, growers can select the cultivar that offers the highest yield potential for their particular situation; however, the knowledge to make these selections accurately each year requires ongoing field research. 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 cultivars provides better information on disease development, lodging, yield potential, yield response, and milling quality 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 this study, therefore, are: 1) to compare the yield potential of commercially available cultivars and advanced experimental lines under commercial production field conditions, 2) to monitor disease pressure in the different regions of Arkansas, and 3) to evaluate the performance of rice cultivars under conditions not commonly observed on experiment stations.

PROCEDURES

Field studies were located in Conway, Craighead, Poinsett, and Randolph counties during this initial study year. Each producer aided in the selection of ten cultivars to be evaluated on their farm. As a result, each site was unique not only in its environmental conditions, but also in cultivars evaluated. Entries selected for each location along with the corresponding seeding date are shown in Table 1. Non-Clearfield entries evaluated during 2013 included Antonio, Caffey, Cheniere, Francis, Jazzman-2, Jupiter, LaKast, Mermentau, Rex, Roy J, Taggart, two University of Arkansas experimental lines (UAEX1102 and UAEX2186), and the RiceTec hybrids XL723 and XL753. Clearfield lines included CL111, CL151, CL152, CL261, and the RiceTec hybrid CLXL745.

Plots were 8 rows (7-inch spacing) wide and 16-ft in length arranged in a randomized complete block design with four replications. Pure-line cultivars (varieties) were seeded at a rate of ~30 seed/ft^2 while hybrids were seeded at a rate of ~14 seed/ft^2. Trials were seeded on 13 May, 9 April, 23 April, and 9 April for Conway, Craighead, Poinsett, and Randolph counties, respectively. 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 and percent total white rice (%HR-%TR). Data were analyzed using analysis of variance, PROC GLM, SAS v. 9.2 (SAS Institute, Inc., Cary, N.C.) with means separated using Fisher's Protected Least Significant Difference test ($P = 0.05$).

RESULTS AND DISCUSSION

During 2013, each site was unique in regard to both location and cultivar selection. Therefore, grain yield is presented by county and corresponding date of seeding (Table 1). In the Conway Co. PREP trial, grain yield averaged 223 bu/acre. The two RiceTec hybrids (XL753 and XL723) and the conventional cultivars LaKast and Mermentau were the highest yielding selections. Jupiter and LaKast were the only cultivars to experience some lodging. In the Craighead Co. PREP trial, grain yield averaged 219 bu/acre during 2013. LaKast, XL753, and Roy J were the highest yielding cultivars. Caffey and Roy J were the highest yielding cultivars in the Poinsett Co. PREP trial, producing grain yields of over 200 bu/acre with Mermentau producing the third highest yield of 183 bu/acre. Several cultivars had problems with lodging in the Poinsett Co. PREP trial, especially Jupiter and LaKast. The hybrid XL753 was the highest yielding cultivar in the Randolph Co. PREP trial followed by LaKast and Mermentau, contributing to a location average yield of 224 bu/acre.

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 2). 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 2013 Producer Rice Evaluation Program provided additional data to the rice breeding and disease resistance programs. The program also provided supplemental performance and disease reaction data on new cultivars that will be more widely grown in Arkansas during 2014.

ACKNOWLEDGMENTS

The authors appreciate the cooperation of all participating rice producers and thank all Arkansas rice growers for financial support through the Rice Check-off funds administered by the Arkansas Rice Research and Promotion Board. The authors especially thank the following county agents who made this work possible: Craig Allen, Mike Andrews, Hank Chaney, Herb Ginn, Mike Hamilton, and Branon Thiesse.

Table 1. Grain yield performance of selected cultivars in the Producer Rice Evaluation Program trials located in grower fields in Arkansas in 2013.

Conway Co. - 13 May[a]			Craighead Co. - 9 April[a]		
Cultivar	Grain yield	Lodging	Cultivar	Grain yield	Lodging
	(bu/acre)	(%)		(bu/acre)	(%)
Antonio	221	0	Caffey	214	0
Cheniere	203	0	CL151	209	0
Jazzman-2	218	0	Francis	212	0
Jupiter	166	48	Jupiter	216	0
LaKast	227	53	LaKast	231	0
Mermentau	231	0	Rex	195	0
Roy J	211	0	Roy J	227	0
RT XL723	269	0	RT XL753	269	0
RT XL753	289	0	UAEX1102	207	0
Taggart	212	0	UAEX2186	206	0
Mean	223	10	Mean	219	0
C.V.[b]	8.6	172.7	C.V.[b]	4.9	n/a
LSD(P =0.05)[c]	28.5	26.2	LSD (P = 0.05)[c]	15.6	n/a

Poinsett Co. - 23 April[a]			Randolph Co. - 9 April[a]		
Cultivar	Grain yield	Lodging	Cultivar	Grain yield	Lodging
	(bu/acre)	(%)		(bu/acre)	(%)
Antonio	153	50	Antonio	226	0
Caffey	221	0	Caffey	224	0
CL111	137	68	Cheniere	210	0
CL261	156	28	CL152	196	0
Jupiter	123	100	Jupiter	208	0
LaKast	137	93	LaKast	241	0
Mermentau	183	0	Mermentau	231	0
Roy J	211	0	Roy J	230	0
RT CLXL745	161	75	RT XL753	256	0
Taggart	166	53	Taggart	219	0
Mean	165	47	Mean	224	0
C.V.[b]	9.4	45.7	C.V.[b]	6.1	n/a
LSD(P = 0.05)[c]	22.4	30.8	LSD(P = 0.05)[c]	19.7	n/a

[a] Planting date.

[b] C.V. = coefficient of variation.

[c] LSD = least significant difference.

Table 2. Rice variety reactions[a] to diseases (2013).

Cultivar	Sheath blight	Blast	Straight-head	Bacterial panicle blight	Narrow brown leaf spot	Stem rot	Kernel smut	False smut	Lodging	Black sheath rot	Sheath spot
Antonio	S	MS		MS		S	S	MS	MS		
LaKast	S	S	MS	S	S	S	S	S	MS	MS	S
Caffey	MS			S	R			MS			
Cheniere	S	VS	VS	VS	S	S	S	S	MR	MS	
CL111	VS	MS	S	VS	VS	VS	S	S	MS	S	
CL142AR	MS	S	MS	S	S	S	S	S	S	S	
CL151	S	VS	VS	VS	S	VS	S	S	MR	S	
CL152	S	VS	S	S	R		VS	S			
CL162	VS	VS		VS	R		S	S	S		
CL261	MS	VS	S	VS	S	VS	MS	S	MS	MS	
Colorado	S	VS		S				S			
Della-2				S							
Francis	MS	VS	MR	VS	S	S	VS	S	MS	S	
Jazzman	MS	S	S	MS	S	S	MS	S	MS	MS	
Jazzman-2	VS	S		VS	MR		S	S			
Jupiter	S	S	S	MR	MS	VS	MS	MS	MS	MR	
Mermentau	S	S	VS	MS			S	S	MS		
Rex	S	S	S	S	MS	S	S	S	MR	S	
Roy J	MS	S	S	S	MR	S	VS	S	MR	MS	
RT CL XL729	MS	R	MS	MR	MS	S	MS	S	S	S	
RT CL XL745	S	R	R	MR	MS	S	MS	S	S	S	S
RT XL723	MS	R	S	MR	MS	S	MS	S	MS	S	
RT XL 753	MS			MR			MS	S		S	
Taggart	MS	MS	R	MS	MS	S	S	S	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. Reactions were determined based on historical and recent observations from test plots and in grower fields across Arkansas. In general, these reactions would be expected under conditions that favor severe disease development including excessive nitrogen rates (most diseases) or low flood depth (blast).

Table prepared by Y. Wamishe, Assistant Professor/Extension Plant Pathologist and R.D. Cartwright, Associate Director - Ag and Natural Resources.

Arkansas Rice Performance Trials

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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 six locations during 2013. Averaged across locations, grain yields were highest for RiceTec XL753, Roy J, and Caffey. Cultivars with the highest head rice yield during 2013 included: Antonio, CL151, CL152, Francis, Jazzman-2, and Mermentau.

INTRODUCTION

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

The Arkansas Rice Performance Trials (ARPTs) are conducted each year to compare promising new experimental lines and newly released cultivars from the breeding programs in Arkansas, Louisiana, Texas, and Mississippi 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 six locations for the 2013 ARPTs included the University of Arkansas System Division of Agriculture 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.; and the Newport Extension Center (NEC) near Newport, Ark., as well as commercial fields at the Louis Ahrent farm in Clay County (CLAY) and the Jason Smith farm in Desha County (DESHA). Ninety entries, which were either promising breeding lines or established cultivars, were grown across the four maturity groups (early, very-short, short, and mid-season).

The studies were seeded at RREC, PTRS, NEREC, NEC, CLAY, and DESHA on 30 April, 20 May, 28 May, 12 June, 14 May, and 15 May, respectively. Pure-line varieties were drill-seeded at a rate of 90 lb seed/acre in plots 8 rows (7-inch spacing) wide and 16 ft in length. Hybrid entries were sown into the same plot configuration using a reduced seeding rate of 33 lb seed/acre. 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, PTRS, and NEC locations. Nitrogen 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 120 lb N/acre on silt loam soils and 150 lb N/acre on clay soils using urea as the N source. The permanent flood was applied within 2 days of pre-flood 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 and percent total rice (%HR - %TR). Each location of the study was arranged in a randomized complete block design with four replications.

RESULTS AND DISCUSSION

The three-year average of agronomic traits, grain yields, and milling yields of selected cultivars evaluated during 2011-2013 are listed in Table 1. The top yielding entries, averaged across three study years, include: RiceTec XL753, Roy J, RiceTec XL723, and Taggart with grain yields of 246, 211, 204, and 204 bu/acre, respectively. Two newer entries, Mermentau and Antonio, also did well with two-year grain yield averages of 200 and 189 bu/acre, respectively. In regard to percent head rice and percent total white rice (%HR - %TR), Antonio, CL151, CL152, Francis, Jazzman-2, and Mermentau had the highest average milling yields from 2011-2013.

Selected agronomic traits, grain yield, and milling yields from the 2013 ARPT are shown in Table 2. RiceTec XL753 was the only cultivar to maintain a grain yield above 200 bu/acre at all locations. Caffey and Roy J were the only other entries to achieve grain yields above 200 bu/acre at the majority of locations. Milling yield, averaged across locations and cultivars, was 63-69 (%HR - %TR) during 2013. The long-grain cultivars CL152 and Francis had the highest milling yields of all commercial entries, averaging 66-70 and 66-71, respectively, across all locations.

The most recent disease ratings for each cultivar are listed in Table 3. Ratings for disease susceptibility should be evaluated critically to optimize cultivar selection. These ratings should not be used as an absolute predictor of cultivar performance with respect to a particular disease in all situations. Ratings are a general guide based on expectations of cultivar reaction under conditions that strongly favor disease; however, environment will modify the actual reaction in different fields.

Growers are encouraged to seed newly released cultivars on a small acreage to evaluate performance under their specific management practices, soils, and environment. Growers are also encouraged to seed rice acreage in several cultivars to reduce the risk of disease epidemics and environmental effects. Cultivars that have been tested under Arkansas growing conditions are more likely to reduce potential risks associated with crop failure.

SIGNIFICANCE OF FINDINGS

Data from this study will assist rice producers in selecting cultivars suitable to the wide range of growing conditions, yield goals, and disease pressure found throughout Arkansas.

ACKNOWLEDGMENTS

The Arkansas Rice Performance Trials are supported through grower Rice Check-off funds administered by the Arkansas Rice Research and Promotion Board. We wish to thank the following people for their dedication to making the ARPT possible each year: Ron Baker, Bethany Berger, Randy Chlapecka, Shawn Clark, Mike Duren, Ambus Handcock, Wes Kirkpatrick, and Chuck Pipkins.

Table 1. Results of the Arkansas Rice Performance

Maturity group and cultivar	Grain length[a]	Straw strength[b]	50% Heading[c]	Plant height	Test weight	Milled kernel wt[d]	Chalky kernels[d]
		(rating)	(days)	(in)	(lb/bu)	(mg)	(%)
Very early season							
CL111	L	2.7	78	40	42.0	20.93	0.833
CL151	L	2.7	79	40	41.4	19.70	1.459
CL162	L	3.0	78	42	40.0	21.22	0.907
Colorado	L	4.0	79	39	40.5	21.60	1.390
RiceTec CL XL729	L	4.7	79	44	41.6	20.26	2.221
RiceTec CL XL745	L	4.7	76	45	41.6	21.28	1.147
RiceTec XL723	L	3.7	79	46	42.0	21.08	2.589
RiceTec XL753	L	2.3	78	43	42.0	20.94	1.668
Early season							
Antonio	L	2.5	81	38	41.9	20.50	1.495
Caffey	M	2.0	82	38	42.3	23.75	1.145
CL142-AR	L	3.3	81	45	42.1	22.14	1.084
CL152	L	1.7	82	39	41.7	17.90	1.110
Francis	L	2.3	81	41	42.2	18.82	1.028
Jazzman-2	L	2.0	80	37	41.6	18.90	0.574
Jupiter	M	2.3	83	38	41.6	20.39	1.003
LaKast	L	3.3	81	43	41.4	20.98	0.875
Mermentau	L	1.5	82	38	41.2	19.40	1.551
Wells	L	2.3	82	42	42.0	21.42	0.954
Mid-season							
RoyJ	L	1.0	86	42	41.5	20.71	0.679
Taggart	L	1.7	84	45	41.9	22.83	0.696
Mean		2.7	81	41	41.6	20.74	1.220

[a] Grain length: L = long-grain; M = medium-grain.

[b] Relative straw strength based on field tests using the scale: 0 = very strong straw, 5 = very weak straw; based on percent lodging.

[c] Number of days from emergence until 50% of the panicles are visibly emerging from the boot.

[d] Data from 2010-2012. Based on weight of 1,000 kernels.

[e] Data from Riceland Grain Quality Lab.

Trials averaged across the three-year period of 2011-2013.

Milling yield by year				Grain yield by year			
2011[e]	2012	2013	Mean	2011	2012	2013	Mean
----------- (% head rice - % total rice)-----------				-------------------- (bu/acre)---------------------			
67-73	62-71	64-69	64-71	158	179	175	171
67-72	63-71	65-70	65-71	142	204	180	175
63-72	59-70	62-69	61-70	166	187	170	174
---	61-70	63-69	62-70	.	174	156	165
62-72	59-70	62-69	61-70	180	203	199	194
64-73	57-72	61-69	61-71	184	205	176	188
67-72	61-71	62-69	63-71	191	222	200	204
66-74	57-71	60-70	61-72	254	246	238	246
---	64-71	65-70	65-71	.	198	180	189
69-74	60-69	58-67	62-70	189	203	203	198
59-73	51-70	60-69	57-71	174	193	186	184
65-70	63-71	66-70	65-70	178	192	160	177
63-70	63-72	66-71	64-71	195	213	196	201
67-72	63-70	66-69	65-70	159	170	160	163
67-73	61-68	61-66	63-69	196	204	194	198
62-70	61-72	63-70	62-71	190	210	197	199
---	65-71	65-69	65-70	.	216	183	200
63-75	54-71	62-70	60-72	182	205	191	193
62-72	64-72	63-70	63-71	196	234	203	211
62-73	56-71	62-69	60-71	215	199	199	204
64-72	60-71	63-69	62-71	185	203	187	192

Table 2. Results of the Arkansas Rice

Maturity group and cultivar	Grain length[a]	Straw strength[b]	50% Heading[c]	Plant height	Test weight	Milling yield
		(rating)	(days)	(in.)	(lb/bu)	(%HR-%TR)
Very early season						
CL111	L	1.0	77	39	40.9	64-69
CL151	L	1.0	79	39	40.3	65-70
CL162	L	2.0	78	41	40.6	62-69
Colorado	L	4.0	76	39	38.8	63-69
RiceTec CLXL729	L	5.0	79	43	40.9	62-69
RiceTec CLXL745	L	5.0	77	44	41.4	61-69
RiceTec XL723	L	4.0	79	44	41.4	62-69
RiceTec XL753	L	2.0	78	42	40.9	60-70
Early season						
Antonio	L	1.0	79	37	41.3	65-70
Caffey	M	2.0	80	38	41.1	58-67
CL142-AR	L	1.0	80	45	40.8	60-69
CL152	L	1.0	81	38	40.8	66-70
Francis	L	1.0	81	40	40.6	66-71
Jazzman-2	L	3.0	79	37	40.8	66-69
Jupiter	M	3.0	82	38	40.1	61-66
LaKast	L	1.0	79	42	40.7	63-70
Mermentau	L	1.0	79	37	40.9	65-69
Wells	L	1.0	81	41	40.7	62-70
Mid-season						
Roy J	L	1.0	85	42	40.5	63-70
Taggart	L	2.0	84	44	40.6	62-69
Mean		2.1	80	41	40.7	63-69

[a] Grain length: L = long-grain; M = medium-grain.

[b] Relative straw strength based on field tests using the scale: 0 = very strong straw, 5 = very weak straw; based on percent lodging.

[c] Number of days from emergence until 50% of the panicles are visibly emerging from the boot.

Performance Trials at six locations during 2013.

Grain yield by location and planting date						
CLAY May 14	DESHA May 15	NEREC May 28	NEC June 12	PTRS May 20	RREC April 30	MEAN
------ (bu/acre) ------						
161	206	148	158	187	190	175
190	134	192	133	209	222	180
154	194	170	132	177	192	170
171	157	170	102	167	170	156
178	156	205	167	237	251	199
156	177	143	162	217	202	176
197	193	178	171	223	237	200
250	256	231	202	238	252	238
184	220	166	124	169	218	180
216	204	217	134	205	240	203
170	220	170	148	191	217	186
151	201	142	115	164	184	160
202	221	193	148	179	231	196
167	188	139	124	156	183	160
192	157	191	163	223	238	194
184	230	184	167	186	233	197
186	220	166	146	175	205	183
198	221	175	165	174	213	191
200	231	204	169	182	233	203
183	238	204	167	175	226	199
185	201	179	150	192	217	187

Table 3. Rice cultivar reactions[a] to diseases (2013).

Cultivar	Sheath blight	Blast	Straight-head	Bacterial panicle blight	Narrow brown leaf spot	Stem rot	Kernel smut	False smut	lodging	Black sheath rot	Sheath spot
Antonio	S	S		MS		S	S	MS	MS		
Bengal	MS	S	VS	VS	S	VS	MS	MS	MR	MR	
Caffey	MS			S	R			MS			
Cheniere	S	VS	VS	VS	S	S	S	S	MR	MS	
CL111	VS	MS	S	VS	VS	VS	S	S	MS	S	
CL142-AR	MS	S	MS	S	S	S	S	S	S	S	
CL 151	S	VS	VS	VS	S	VS	S	S	MR	S	
CL 152	S	VS	S	S	R		VS	S			
CL 162	VS	VS		VS	R		S	S	S		
CL 261	MS	VS	S	VS	S	VS	MS	S	MS	MS	
Cocodrie	S	S	VS	S	S	VS	S	S	MR	S	
Colorado	S	VS		S				S			
Della-2				S							
Francis	MS	VS	MR	VS	S	S	VS	S	MS	S	
Jazzman	MS	S	S	MS	S	S	MS	S	MS	MS	
Jazzman-2	VS	S		VS	MR		S	S			
JES	S	R	VS	S	R	VS	MS	MS	S	MR	
Jupiter	S	S	S	MR	MS	VS	MS	MS	MS	MR	
LaKast	S	S	MS	S	S	S	S	S	MS	MS	S
Mermentau	S	S	VS	MS			S	S	MS		
Rex	S	S	S	S	MS	S	S	S	MR	S	
Roy J	MS	S	S	S	MR	S	VS	S	MR	MS	
RiceTec CL XL729	MS	R	MS	MR	MS	S	MS	S	S	S	
RiceTec CL XL745	S	R	R	MR	MS	S	MS	S	S	S	S
RiceTec CL XP756	MS							S		S	
RiceTec XL723	MS	R	S	MR	MS	S	MS	S	MS	S	
RiceTec XL753	MS			MR			MS	S		S	
RiceTec XP754	MS							S		S	S
Taggart	MS	MS	R	MS	MS	S	S	S	MS	MS	

continued

Table 3. Continued.

Cultivar	Sheath blight	Blast	Straight-head	Bacterial panicle blight	Narrow brown leaf spot	Stem rot	Kernel smut	False smut	lodging	Black sheath rot	Sheath spot
Templeton	MS	R	S	MS	S	MS	S	S	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. Reactions were determined based on historical and recent observations from test plots and in grower fields across Arkansas. In general, these reactions would be expected under conditions that favor severe disease development including excessive nitrogen rates (most diseases) or low flood depth (blast).

Table prepared by Y. Wamishe, Assistant Professor/Extension Plant Pathologist and R.D. Cartwright, Associate Director - Ag and Natural Resources.

Effects of Insecticide Seed Treatments and Seeding Rates on Performance of Selected Rice Cultivars at Two Planting Dates

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ABSTRACT

The use of insecticide seed treatments in rice has increased rapidly in recent years. At the same time, producers have decreased rice seeding rates. Trials were conducted in 2013 to evaluate the effects of insecticide seed treatments on rice performance across a range of seeding rates. The objective of this study was to evaluate the rice seeding rates with and without an insecticide seed treatment. The cultivars CL152 and Roy J were seeded at rates of 30, 40, 50, 60, and 70 lb/acre while RiceTec hybrid XL753 was seeded at rates of 10, 15, 20, 25, and 30 lb/acre. All seed was treated with the same base fungicide package while insecticide-treated plots also received thiamethoxam (CruiserMaxx Rice), chlorantraniliprole (Dermacor X-100), or an untreated control (fungicide only). Trials were planted in early April and early June. Across all seeding rates and cultivars in the April planting date, CruiserMaxx Rice- and Dermacor-treated rice seed had significantly higher stand counts than untreated seed. In the April planting date, CruiserMaxx Rice- and Dermacor-treated seed significantly increased grain yield compared to the untreated seed, averaged across cultivars and seeding rates; while in the June planting date, rice from Dermacor-treated seed produced significantly more grain yield than both CruiserMaxx Rice-treated seed and the untreated control.

INTRODUCTION

In recent years, the use of insecticide seed treatments in rice has steadily increased. These seed treatments initially gained favor for their effective control of grape colaspis and rice water weevil. Their use increased further as additional benefits were observed, including increased early-season plant growth and vigor, and increased yield even in the absence of insect pressure. While the use of insecticide seed treatments has increased, rice seeding rates have been progressively decreasing as producers attempt to minimize input costs. In addition to reduced input costs, lower seeding rates are often associated with reduced lodging and disease pressure. Little is known about the impact of reduced seeding rates on insecticide seed treatments in rice.

The objective of this research was to evaluate the interaction between insecticide seed treatments and seeding rates on rice plant stand, grain yield, and milling yield.

PROCEDURES

The study was conducted during 2013 at the University of Arkansas System Division of Agriculture Rice Research and Extension Center (RREC) near Stuttgart, Ark., on a DeWitt silt loam soil. Three rice cultivars, CL152, Roy J, and RiceTec XL753, were drill-seeded in plots 9 rows (7-inch spacing) wide and 16 ft in length. CL152 and Roy J were seeded at 30, 40, 50, 60, and 70 lb/acre and the hybrid RTXL753 was seeded at 10, 15, 20, 25, and 30 lb/acre. General seeding, seedling emergence, and flood dates are shown in Table 1. Plots were seeded on 9 April and 5 June at the RREC. Normal cultural practices for dry-seeded, delayed-flood rice were followed throughout the season. All plots received 120 lb N/acre as a single preflood application of urea at the 4- to 5-lf growth stage. The permanent flood was applied and maintained until rice reached maturity. Data collected included: stand counts at the 3- to 4-lf growth stage, grain yield, and milling yield. At maturity, the center 5 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. Each planting date was arranged in a randomized complete block design with four replications. Statistical analyses were conducted using PROC GLM, SAS v. 9.2 (SAS Institute, Inc., Cary, N.C.) and mean separations were conducted based upon Fisher's Protected Least Significant Difference test ($P = 0.05$) where appropriate.

RESULTS AND DISCUSSION

Analysis of variance indicated the three-way interaction of cultivar × seed treatment × seeding rate was not significant for plant stand for either the April or June planting dates. In the April planting date, rice receiving an insecticide seed treatment displayed an increase in the number of plants per square feet (ft^2) at each seeding rate compared to untreated rice seed (Fig. 1). The difference between rice with insecticide seed treatments and rice with untreated seed was significant when averaged across seeding rates and cultivars (Fig. 2). In the June planting date, the same trend was again observed across seeding rates, but was less pronounced, possibly due to the test being flushed in order to achieve a successful stand across the test area (Fig. 3). When averaged across seeding rates and cultivars, no significant differences were observed (Fig. 2).

Analysis of variance indicated the three-way interaction of cultivar × seed treatment × seeding rate was not significant for grain yield for either the April or June planting dates. For grain yield in the April planting date, the rice with the insecticide seed treatment produced higher yields at each seeding rate compared to the untreated rice seed (Fig. 4). However, yield trends for insecticide seed treatments and untreated seed were similar at the highest seeding rates. Averaged across seeding rates and cultivars, CruiserMaxx Rice and Dermacor X-100 produced significantly higher yields compared to untreated seed for the April planting date (Fig. 5).

For grain yield in the June planting date, rice with the insecticide seed treatment again produced higher yields at each seeding rate compared to rice with the untreated seed (Fig. 6). Similar to the April planting date, the yield advantage of insecticide seed treatments did appear to be greatest at the lower seeding rates. When averaged across seeding rates and cultivars, rice with seed treated with Dermacor X-100 produced significantly greater yields compared to rice with seed treated with CruiserMaxx Rice and rice with untreated seed (Fig. 5). The significant difference between Dermacor X-100 and CruiserMaxx Rice in the June-planted trial is believed to be attributed to the need to flush the trial early in the season to establish a stand. CruiserMaxx Rice is known to be more water soluble than Dermacor X-100 and may have been negatively impacted by the need for early season flushes. This would explain the lack of a significant response for this insecticide seed treatment compared to the untreated seed or control.

SIGNIFICANCE OF FINDINGS

The data from this preliminary study agree with previous research that supports positive agronomic and yield benefits associated with the use of insecticide seed treatments. In addition, this study suggests that insecticide seed treatments can provide an even greater benefit when lower seeding rates are used. This study needs to be repeated in years with more ‘normal’ environmental conditions to fully evaluate the relationship between insecticide seed treatments and seeding rates.

ACKNOWLEDGMENTS

This research was funded by the Arkansas Rice Research and Promotion Board. Special thanks are extended to Emmett ‘Chuck’ Pipkins and Bethany Berger for their assistance with this project.

Table 1. General seeding, seedling emergence, and flooding date information for the insecticide seed treatment and seeding rate studies at the Rice Research and Extension Center.

Parameter	Dates/days	
Seeding date	9 April	5 June
Emergence date	24 April	13 June
Flood date	7 June	5 July
Days from seeding to emergence	15	8
Days from seeding to flooding	59	30
Days from emergence to flooding	44	22

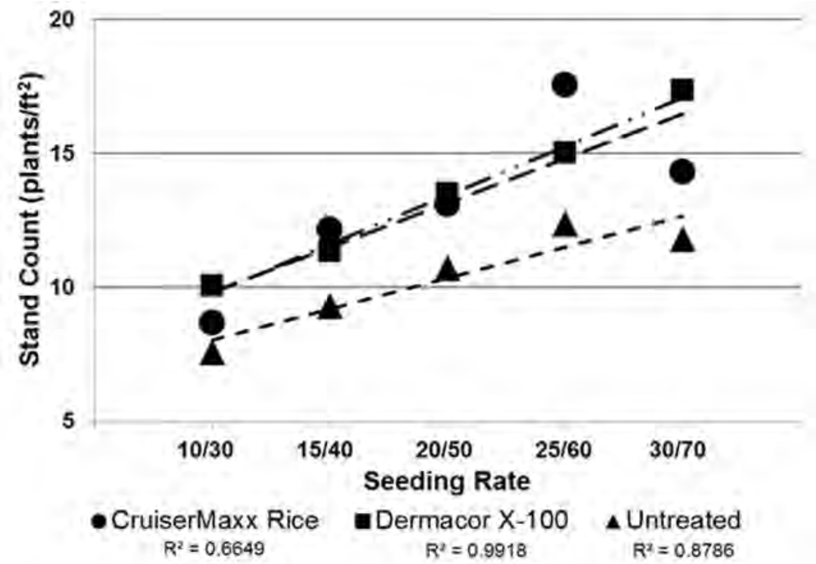

Fig. 1. Influence of insecticide seed treatment and seeding rate on plant stand averaged across cultivars (CL152, Roy J, and RiceTec XL753) for the 9 April planting date at the Rice Research and Extension Center, 2013.

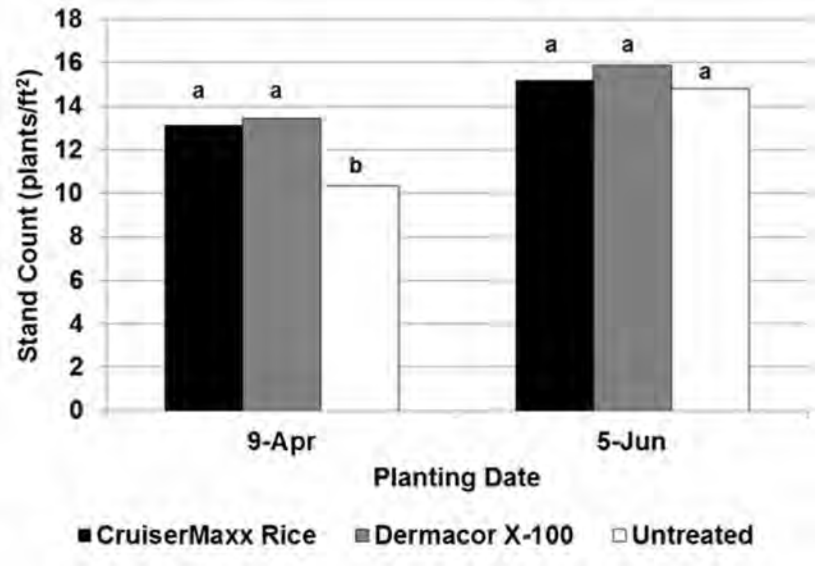

Fig. 2. Influence of insecticide seed treatment on plant stand averaged across seeding rates and cultivars (CL152, Roy J, and RiceTec XL753) in studies at the Rice Research and Extension Center, 2013.

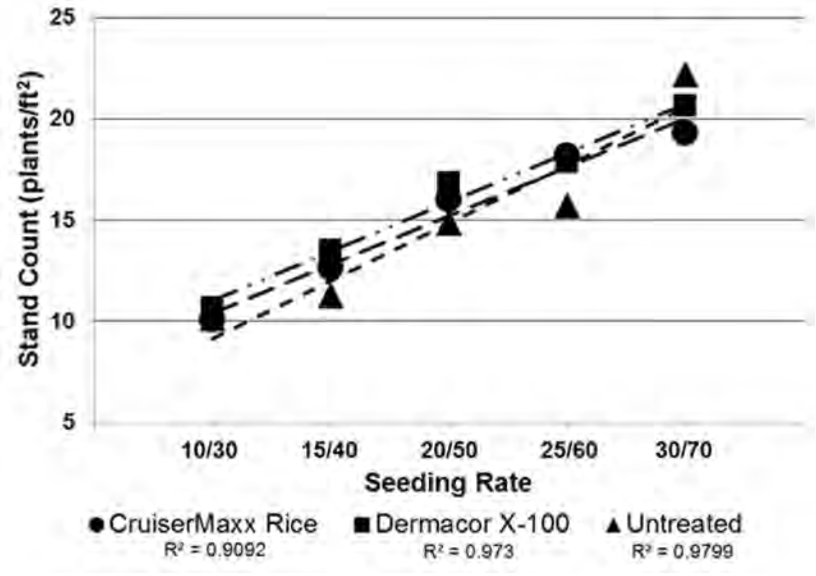

Fig. 3. Influence of insecticide seed treatment and seeding rate on plant stand averaged across cultivars (CL152, Roy J, and RiceTec XL753) for the 5 June planting date at the Rice Research and Extension Center, 2013.

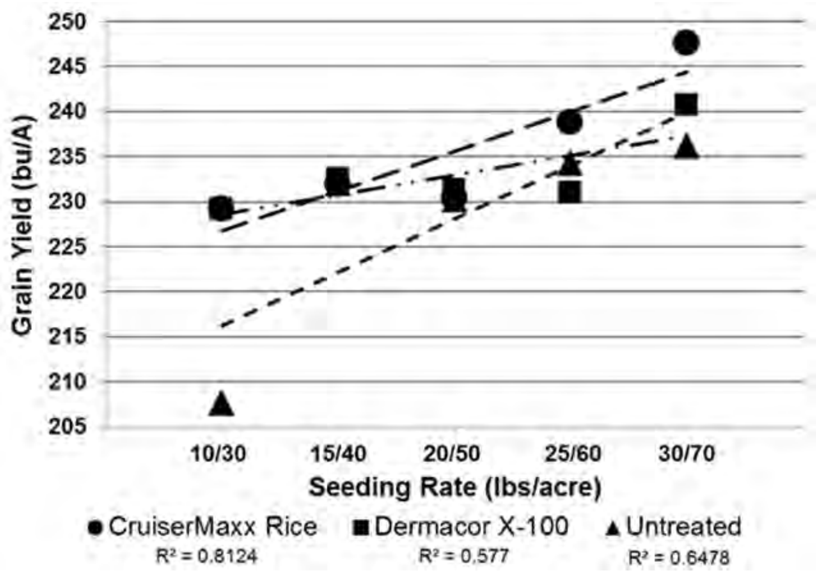

Fig. 4. Influence of insecticide seed treatment and seeding rate on grain yield averaged across cultivars (CL152, Roy J, and RiceTec XL753) for the 9 April planting date at the Rice Research and Extension Center, 2013.

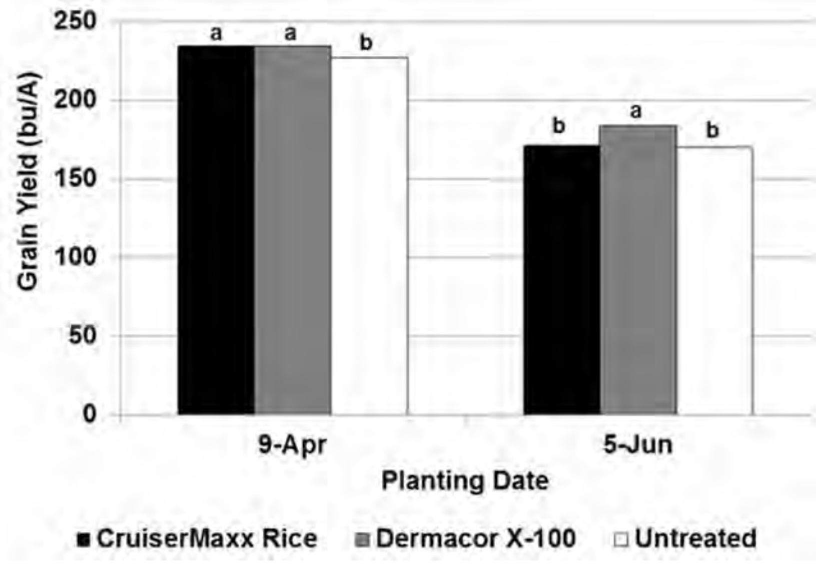

Fig. 5. Influence of insecticide seed treatment on grain yield averaged across seeding rates and cultivars (CL152, Roy J, and RiceTec XL753) in studies at the Rice Research and Extension Center, 2013.

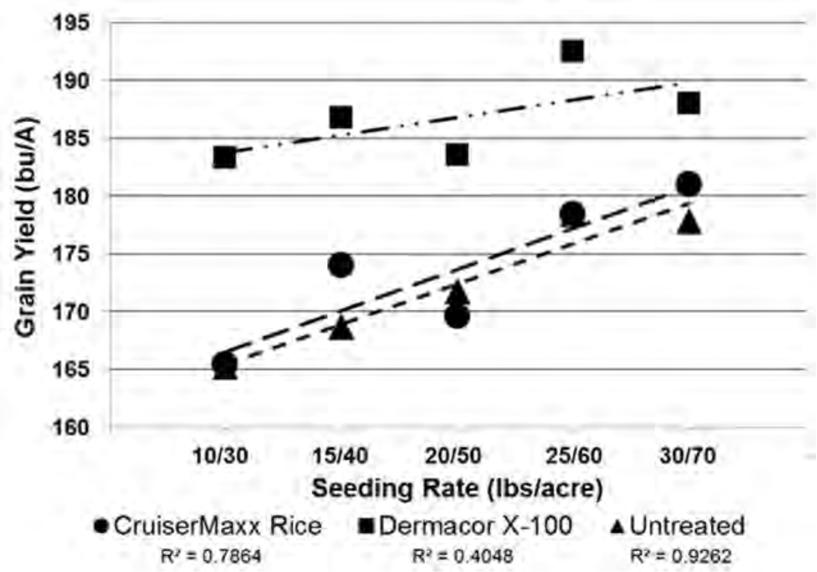

Fig. 6. Influence of insecticide seed treatment and seeding rate on grain yield averaged across cultivars (CL152, Roy J, and XL753) for the 5 June planting date at the Rice Research and Extension Center, 2013.

Evaluation of Optimum Hybrid Rice Seeding Rates on Silt Loam and Clay Soils

J.T. Hardke, D.L. Frizzell, E. Castaneda-Gonzalez, M. Duren, and R.J. Norman

ABSTRACT

Two trials were conducted in 2013 to evaluate the performance of several hybrid rice cultivars at various seeding rates. Three RiceTec hybrids, XL753, CLXL745, and CLXL729, were seeded at rates of 10, 15, 20, 25, and 30 pounds (lb) per acre. The trials were conducted at the University of Arkansas System Division of Agriculture Rice Research and Extension Center (RREC) near Stuttgart, Ark., on a silt loam soil and at the Northeast Research and Extension Center (NEREC) near Keiser, Ark., on a silty clay soil. Grain and milling yields were measured at maturity to evaluate the influence of seeding rate on grain and milling yield potential. Increased grain yield was observed as seeding rate increased, while milling yields (head rice and total milled rice) were similar across seeding rates.

INTRODUCTION

Hybrid rice is typically seeded at reduced rates compared to most conventional varieties. Current recommendations under optimum conditions are to plant hybrid rice at approximately 12 seed/ft^2 or 25 lb seed/acre with the goal of achieving a plant stand of 6 to 10 plants/ft^2. In an effort to lower input costs, rice growers have recently begun to plant hybrids at reduced seeding rates. As a result, there have been questions concerning the potential grain and milling yield response of hybrids across reduced seeding rates. However, soil texture should also be considered when selecting an optimal seeding rate for a particular field. Therefore, the objective of this study was to evaluate the effect of seeding rate on grain yield and milling yield of selected hybrid rice cultivars on silt loam and clay soils.

PROCEDURES

The study was conducted during 2013 at the University of Arkansas System Division of Agriculture Rice Research and Extension Center (RREC) near Stuttgart, Ark., on a DeWitt silt loam soil; and at the Northeast Research and Extension Center (NEREC) near Keiser, Ark., on a Sharkey silty clay soil. Three hybrid rice cultivars (RiceTec CLXL729, CLXL745, and XL753) were drill-seeded at rates 10, 15, 20, 25, and 30 lb seed/acre in plots 9 rows (7-inch spacing) wide and 16 ft in length. General seeding, seedling emergence, and flood dates are shown in Table 1. Plots were seeded on 9 April at RREC and on 28 May at NEREC. Normal cultural practices for dry-seeded, delayed-flood rice were followed. All plots received 120 lb nitrogen (N)/acre (RREC) or 150 lb N/acre (NEREC) as a single preflood application of urea at the 4- to 5-lf growth stage. The permanent flood was applied and maintained until rice reached maturity. Data collected included: stand counts and plant heights at the 2- to 3-lf growth stage, grain yield, and milling yield. 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 and percent total white rice. Each seeding date was arranged in a randomized complete block design with four replications. Linear regression analysis ($P < 0.05$) was performed with PROC REG in SAS v 9.2 (SAS Institute, Inc., Cary, N.C.)

RESULTS AND DISCUSSION

In 2013, a positive relationship was observed between seeding rate and grain yield at RREC and NEREC. At RREC, grain yield increased from 216 bu/acre at 10 lb seed/acre to 245 bu/acre at 30 lb seed/acre for CLXL729; from 205 bu/acre at 10 lb seed/acre to 207 bu/acre at 30 lb seed/acre for CLXL745; and from 222 bu/acre at 10 lb seed/acre to 249 bu/acre at 30 lb seed/acre for XL753 (Fig. 1). At NEREC, grain yield increased from 135 bu/acre at 10 lb seed/acre to 179 bu/acre at 30 lb/acre for CLXL729; from 80 bu/acre at 10 lb seed/acre to 127 bu/acre at 30 lb seed/acre for CLXL745; and from 128 bu/acre at 10 lb seed/acre to 167 bu/acre at 30 lb seed/acre for XL753 (Fig. 2). Averaged across cultivars, grain yield ranged from 214 bu/acre at 10 lb seed/acre to 233 bu/acre at 30 lb seed/acre at RREC; and from 113 bu/acre at 10 lb seed/acre to 157 bu/acre at 30 lb seed/acre at NEREC. While differences were observed in milling yield between cultivars, there was no milling yield response to seeding rate at either location (Tables 2 and 3).

Despite recent interest in reduced seeding rates for hybrid rice cultivars, the current data suggests a positive relationship between grain yield and seeding rate. Given current seed costs of hybrid rice, a yield increase of approximately 2 bu/acre is needed to justify planting an additional 5 lb seed/acre. In the current study, increasing hybrid seeding rate by 5 lb seed/acre generated a positive return of 5 to 10 bu/acre. This suggests that increased seeding rates for hybrids are more profitable than decreased seeding rates.

SIGNIFICANCE OF FINDINGS

The data from this preliminary study suggest that higher seeding rates provide a sufficient increase in yield to justify the added cost of increased seeding rates. This study needs to be repeated in years with more 'normal' environmental conditions to fully evaluate the effects of hybrid seeding rate on grain yield and milling yield.

ACKNOWLEDGMENTS

This research was funded by the Arkansas Rice Research and Promotion Board. Special thanks are extended to Emmett 'Chuck' Pipkins and Bethany Berger for their assistance with this project.

Table 1. General seeding, seedling emergence, and flooding date information for hybrid seeding rate studies in 2013 at the Rice Research and Extension Center (RREC) and Northeast Research and Extension Center (NEREC).

Parameter	RREC	NEREC
Seeding date	9 April	28 May
Emergence date	24 April	9 June
Flood date	7 June	2 July
Days from seeding to emergence	15	12
Days from seeding to flooding	59	35
Days from emergence to flooding	44	23

Table 2. Influence of seeding rate on milling yield of selected rice cultivars in studies conducted at the Rice Research and Extension Center during 2013.

	Milling yield[a] by seeding rate					
Cultivar	10	15	20	25	30	Mean
	(%HR - %TR)					
CLXL729	62-68	61-68	61-67	61-68	61-68	61-68
CLXL745	62-69	63-69	62-69	61-69	62-69	62-69
XL753	63-69	63-70	62-69	63-70	62-70	63-70
Mean	62-69	62-69	62-69	62-69	62-69	

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

Table 3. Influence of seeding rate on milling yield of selected rice cultivars in studies conducted at the Northeast Research and Extension Center during 2013.

	Milling yield[a] by seeding rate					
Cultivar	10	15	20	25	30	Mean
	(%HR - %TR)					
CLXL729	64-68	64-68	64-68	64-69	63-68	64-68
CLXL745	62-68	62-69	61-69	62-69	62-69	62-69
XL753	59-68	60-69	59-69	59-69	59-69	59-69
Mean	62-68	62-69	62-68	62-69	61-69	

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

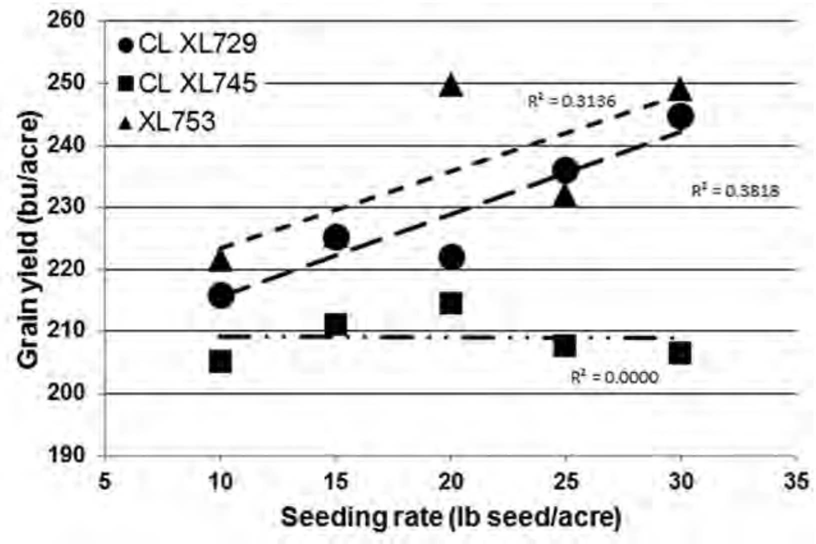

Fig. 1. Influence of seeding rate on grain yield of selected hybrid rice cultivars in studies conducted at the Rice Research and Extension Center during 2013.

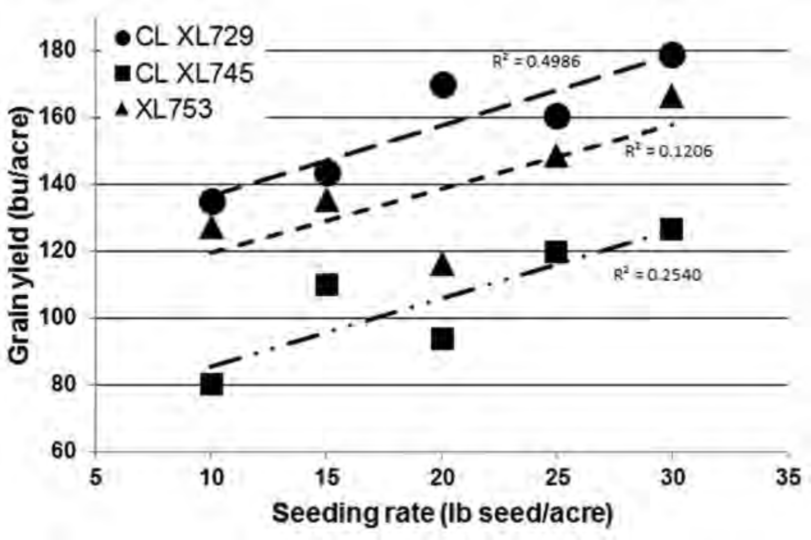

Fig. 2. Influence of seeding rate on grain yield of selected hybrid rice cultivars in studies conducted at the Northeast Research and Extension Center during 2013.

Irrigation Water Requirements for Rice Irrigation Systems in Arkansas

C.G. Henry, E.D. Vories, M.M. Anders, S.L. Hirsh,
M.L. Reba, K.B. Watkins, and J.T. Hardke

ABSTRACT

This study investigated rice irrigation water use in the University of Arkansas Rice Research Verification Program between the years of 2003 and 2012. Annual irrigation water use averaged 763 mm (30.0 inches) over 10 years. A significant (40%) water savings was found for rice grown using a zero-grade irrigation system (486 mm or 19.1 inches) compared to contour- or straight-levee systems. No differences in irrigation water use were found between contour-levee systems (814 mm or 32.1 inches) and straight-levee systems (822 mm or 32.4 inches).

INTRODUCTION

Throughout Arkansas, Louisiana, and Mississippi, the three predominant land forms used for rice production are contour levees, precision graded or straight levees, and zero grade. Levees are typically approximately 30 cm to 45 cm (12 to 18 inches) in height and are constructed, after dry seeding the crop, on grade every 3 to 9 cm (0.1 to 0.3 ft) to allow for a flood to be maintained on the paddy area between levees. Contour-levee fields have minimal land improvements and the levees follow the natural contour of the land. Irrigation water is applied at the top of the field and cascades through the paddies via levee gates or spillways. Upper paddies must be filled before water is distributed to lower paddies. This water management system is used to maintain a flood without the additional cost of land leveling. Straight levees, as a result of precision grading, involve adjusting the grade to a desired slope before levees are constructed. This approach facilitates the use of furrow irrigation on crops rotated with rice and is usually less costly to construct than zero-grade systems.

Traditional flooded rice production consists of a well or riser located in the highest-elevation portion of the field. Water spills into lower paddies as the upper paddies fill. In an alternative method, known as multiple-inlet irrigation, rather than the water being discharged directly into the highest paddy, a disposable, low pressure pipe (polypipe) is connected to the water source and laid either next to or across paddies extending down the field. Gates or holes are placed in the polypipe within each paddy so that all paddies are concurrently watered instead of receiving overflow from a higher paddy. Multiple inlet can be used on either contour- or straight-levee fields.

Zero-grade fields are precision graded in all directions to have little to no grade to minimize the flood depth variation. A small canal is built on three or four sides of the field. Water is pumped into the canal at a single or multiple sites and the field is flooded from multiple sides. Most growers using this land form provide small ditches (drain furrows) across the field for faster water distribution. An advantage of this system is that the entire field can be quickly flooded and the flood depth is constant across the field. A disadvantage of zero grade is that these fields do not drain as well as sloping fields, which is a concern for crops rotated with rice. Therefore, many producers opt for continuous rice production in zero-grade fields. In Arkansas, Wilson et al. (2008) reported that between 2006 and 2008, about 51% of the total rice acres in Arkansas were in contour levees, 43% in straight levees, and 6% in zero grade fields.

PROCEDURES

In this paper we present on-farm water use information from 10 years of the Rice Research Verification Program (RRVP) in Arkansas between 2003 and 2012. Irrigation water use in the RRVP was measured using portable McCrometer® propeller-style flow meters (McCrometer, Inc., Hemet, Calif.) that are installed on grower fields during the crop season. The coordinators of the RRVP read the totalizers at the beginning, during, and end of the season to determine irrigation water use. Rainfall amounts at each location were collected using manually read rain gauges or tipping bucket rain gauges. Coordinators visited sites each week during the growing season. The dataset from the RRVP for 2003 to 2012 included year, soil texture (e.g. clay, silt loam), multiple inlet use information, water source (e.g. well, surface), irrigation water use, total water use, and rice yield. In addition, the dataset from 2005 to 2012 included irrigation system type (contour levee, straight levee, multiple inlet, zero grade), and the dataset from 2008 to 2012 included pump type (e.g. electric, diesel). All data used in this analysis were derived from the published annual RRVP reports. The authors checked the data for completeness and reasonableness. The data were cross-checked where possible between the published reports and manuscripts, spreadsheets, and other internal documents and files to ensure the data were reasonable and accurate. Inconsistent data were either excluded or corrected.

Analysis of variance evaluations were performed using a general linear models (GLM) procedure in SAS v. 9.3 (SAS Institute, Inc., Cary, N.C.). Data collection was not consistent over years which resulted in a need to 'group' data parameters such as irrigation system, irrigation management, soil type, and pump type variables that could be compared across a number of years. There was no replication at each site, thus the site was used as a replication within each year. Least squares means (LSM) were determined, and Tukey's honestly significant difference test was used to determine treatment differences at the significance level of $P < 0.05$.

Three separate ANOVA tests were computed to appropriately analyze each of the irrigation system types for irrigation water use and total water use. First, the data from 2005 to 2012 were analyzed using soil texture and irrigation system type (N = 84). Second, the data from 2005 to 2012 were analyzed using a soil texture, two of the three irrigation system types, and whether or not multiple inlet irrigation management was used (N = 72). Fields using the zero-grade irrigation system were not included in this analysis because the multiple inlet variable does not apply to the zero-grade irrigation system; zero-grade irrigation systems inherently use a single water-entry point and there is no expected water savings from using multiple inlet with a zero-grade system. Third, the data from 2003 to 2012 were analyzed according to soil texture and whether or not they used multiple inlet irrigation (N = 94). The irrigation system type variable was not included in this analysis because it was not reported in the RRVP data from 2003 to 2004. Again, fields using the zero-grade irrigation system were not included in this analysis because the multiple inlet variable does not apply. The 2003 to 2012 dataset was analyzed to determine effects of multiple inlet use on yield. In addition, the 2003 to 2012 dataset was analyzed to determine the effects of water source on irrigation water use and irrigation pumping cost per acre (N =105). The 2008 to 2012 data were analyzed to determine effects of the pump type on irrigation water use and irrigation cost per acre (N = 53). Yield by irrigation and total water use was analyzed (yield/m^3 irrigation or total water use), to determine if total water use was related to grain yield. The same trends and conclusions were drawn from this analysis as is presented below, so these results were not included.

RESULTS AND DISCUSSION

Irrigation water use, by year, from 2003 to 2012 is presented in Table 1. From 2003 to 2012, irrigation water use by field ranged from 254 mm (10.0 inches) to 1,880 mm (74.0 inches), with an average of 763 mm (30.0 inches). Irrigation water use was significantly higher in 2005 (985 mm; 38.8 inches) than in 2004 (621 mm; 24.4 inches), and in 2005 than in 2008 (620 mm; 24.4 inches). There was significantly more rain (growing season only) in 2009 than in every other year from 2003 to 2012. In addition, 2005 had significantly less rain than 2004 and 2011. Total water applied (irrigation plus rain) to fields ranged from 559 mm (22.0 inches) to 2283 mm (90.0 inches), with an average of 1136 mm (44.7 inches). Total water applied was not significantly different between any of the years from 2003 to 2012. Rice yield was not related to irrigation water use or total water use (Fig. 1).

Irrigation water use of 763 mm (30.0 inches) from 2003 to 2012 (Table 1) was 17 mm (0.7 inches) less than the 2003 to 2005 average of 780 mm (30.7 inches) for

Arkansas reported by Vories et al. (2006), and 132 mm (5.2 inches) less than the 2003 to 2004 Mississippi average of 895 mm (35.2 inches) reported by Smith et al. (2007). Growers may have improved their efficiency in overall water management or a short-term cycle of wetter climate may explain this trend. In addition, the Vories et al. (2006) dataset may simply include more relatively dry years than this 2003 to 2012 dataset. Additionally, the Vories et al. (2006) dataset used preliminary data for 2005 and there was a small discrepancy between some of the data points compared to the published verification report. One concern the authors share is the potential for human error and lack of quality control of the data. For example sometimes coordinators would estimate flushes because the meters were not installed in time or may not have known that the field was flushed. However, it is the best and only available historical data of its kind available for Arkansas and the mid-South. Furthermore, this information will help the researchers determine which factors to concentrate on in future studies.

Soil Texture Differences

In Arkansas, rice is generally grown in flooded paddies and on soils that have low permeability. In some locations, a clay pan retards deep percolation, allowing for the soils to maintain a permanent flood. In the 2003 to 2012 analysis of soil texture and multiple inlet use, there were significant differences in the irrigation water use between clay (700 mm; 27.6 inches) and silt loam (845 mm; 33.3 inches) soil textures ($P = 0.01$). Silt loam soils used an average of 145 mm (5.7 inches) more irrigation water than clay soils. However, in the 2005 to 2012 analysis of soil texture and land form and the 2003 to 2012 analysis of soil texture, land form, and multiple inlet use, there were no significant differences in the irrigation water use between clay and silt loam soil textures ($P = 0.09$ and $P = 0.16$, respectively). In the 2003 to 2012 analysis of soil texture and multiple inlet use, there were significant differences in the total water use between clay (1068 mm; 42.0 inches) and silt loam (1223 mm; 48.2 inches) soil textures ($P = 0.02$). In the 2005 to 2012 analysis of soil texture, land form, and multiple inlet use, there were significant differences in the total water use between clay (1098 mm; 43.2 inches) and silt loam (1296 mm; 51.0 inches) soil textures ($P = 0.02$). However, in the 2005 to 2012 analysis of soil texture and irrigation system type, there were no significant differences in the irrigation water use between clay and silt loam soil textures ($P = 0.08$). These findings suggest variability in the dataset or that other factors play a role in water use.

Irrigation System Type

Water use data collected in 2005 to 2012 from rice fields in the RRVP indicated there were no water savings realized when precision-graded, straight-levee fields were compared to non-graded, contour-levee fields. However, a significant reduction in irrigation water use (40%) was realized when comparing zero-grade to contour-levee ($P = 0.004$) or straight-levee ($P = 0.002$) systems, although fewer zero-grade fields were included in the comparison (Table 2). Figure 2 summarizes irrigation water use by irrigation system and soil texture. There were no differences in the irrigation water use between clay or silt loam fields within straight-levee, contour-levee, or zero-grade fields (interaction of soil texture by irrigation system type, $P = 0.41$).

SIGNIFICANCE OF FINDINGS

This study investigated irrigation water use in rice from the University of Arkansas Rice Research Verification Program between the years of 2003 and 2012. For this time period, rice producers applied an average of 763 mm (30.0 inches) of irrigation water. This is 17 mm (0.7 inch) less irrigation water than reported by Vories et al. (2006) for 2003 to 2005. Water use ranged between 254 and 1,880 mm (10.0 and 74.0 inches). From 2003 to 2012, silt loam soils annually applied, on average, 145 mm (5.7 inches) more irrigation water than clay soils (845 mm versus 700 mm). A significant 40% water savings was reported for rice grown under a zero-grade irrigation system (486 mm) compared to contour- and straight-levee systems, although fewer zero-grade fields were included in the dataset. No difference in irrigation water use was found between contour-levee fields (814 mm) and straight-levee fields (822 mm).

ACKNOWLEDGMENTS

The authors would like to thank Phil Tacker and all the past verification coordinators and faculty project leaders throughout the history of the RRVP program for their efforts in collecting these data. These data would not have been available without the long-term financial support of the Arkansas Rice Research and Promotion Board.

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Table 1. Irrigation water use and precipitation for rice in Arkansas by year (2003 to 2012).

Year	n	Annual average irrigation water use	Annual irrigation water use range	Growing season average precipitation	Growing season average precipitation range	Total water-irrigation plus precipitation
		-----------	-----------	[mm (inches)]	-----------	-----------
2003	10	724 (28.5)	478-973 (18.8-38.3)	333 (13.1)	173-569 (6.8-22.4)	1057 (41.6)
2004	10	621 (24.4)	460-889 (18.1-35.0)	424 (16.7)	297-622 (11.7-24.5)	1045 (41.1)
2005	15	985 (38.8)	690-1431 (27.2-56.3)	250 (9.8)	79-335 (3.1-13.2)	1235 (48.6)
2006	11	871 (34.3)	356-1245 (14.0-49.0)	296 (11.6)	152-457 (6.0-18.0)	1167 (45.9)
2007	9	683 (26.9)	330-1118 (13.0-44.0)	294 (11.6)	203-356 (8.0-14.0)	977 (38.5)
2008	12	620 (24.4)	254-889 (10.0-35.0)	343 (13.5)	102-711 (4.0-28.0)	963 (37.9)
2009	13	677 (26.6)	356-1179 (14.0-46.4)	666 (26.2)	356-991 (14.0-39.0)	1343 (52.8)
2010	9	955 (37.6)	500-1880 (19.7-74.0)	307 (12.1)	107-423 (4.2-16.7)	1262 (49.7)
2011	12	687 (27.1)	508-965 (20.0-38.0)	464 (18.3)	234-655 (9.2-25.8)	1151 (45.4)
2012	8	764 (30.1)	445-1151 (17.5-45.3)	289 (11.4)	168-465 (6.6-18.3)	1053 (41.5)
Average[†]		763 (30.0)		373 (14.7)		
SD		280 (11.0)		175 (6.9)		

[†] Average and standard deviation (SD) values are for the entire dataset.

Table 2. Irrigation water use for rice in Arkansas by irrigation system type (2005 to 2012).

Irrigation system type	n	Average irrigation water use	Range	Standard error
		[mm (inches)]		
Contour	33	814 (32.1)a[†]	406-1430 (16.0 - 56.3)	49.8 (2.0)
Straight levee	39	822 (32.4)a	356-1880 (14.0 - 74.0)	44.1 (1.7)
Zero grade	12	486 (19.1)b	254-864 (10.0 - 34.0)	84.3 (3.3)

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

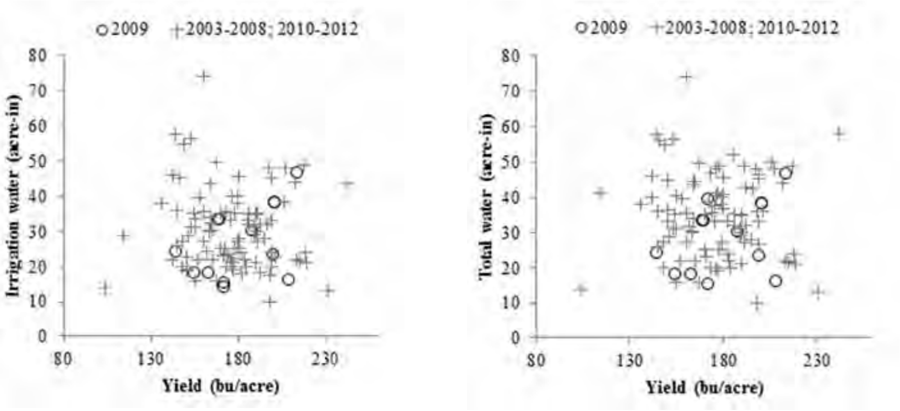

Fig. 1. Relationship between yield and irrigation water use (left) and total water use (right) for years of 2003 to 2012.

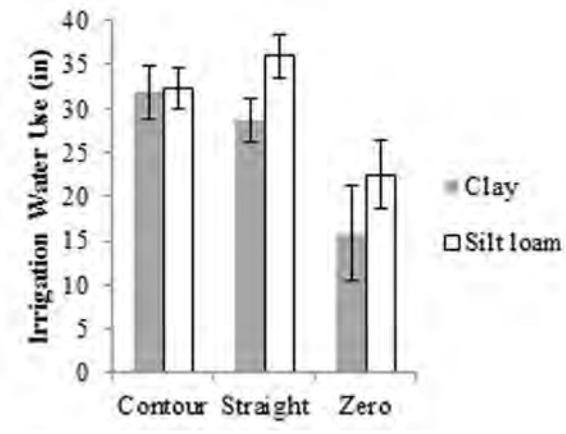

Fig. 2. Irrigation water use by irrigation system type, indicating soil texture (2005 to 2012).

Grain Yield Response of Eight New Rice Cultivars to Nitrogen Fertilization

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ABSTRACT

The Variety × Nitrogen (N) Fertilizer Rate Study determines the proper N fertilizer rates for the new rice varieties across the array of soil and climatic conditions which exist in the Arkansas rice growing region. The eight rice varieties studied in 2013 were: Antonio, Caffey, Horizon Ag's Clearfield CL152, Colorado, Della2, Jazzman2, LaKast, and Mermentau. Cool, wet weather and muddy soil conditions caused us to have to delay planting, but surprisingly rice grain yields in commercial fields in Arkansas in 2013 broke the record set in 2012. Lodging was not an issue for any of the varieties at any of the three locations in 2013. The most prudent N fertilizer recommendation for Antonio, Caffey, Della2, and Jazzman2 to maximize grain yield and minimize lodging when grown on most silt loam soils would be to apply 135 lb N/acre in a two-way split application of 90 lb N/acre at preflood and 45 lb N/acre at midseason; and when grown on clay soils the preflood N rate should be increased by 30 lb N/acre to 120 lb N/acre. The results for Colorado and Mermentau indicated an N rate range would be the best recommendation. When Colorado and Mermentau are grown on silt loam soils a total N rate range of 135 to 150 lb N/acre should be applied in a two-way split application of 90 to 105 lb N/acre at preflood and 45 lb N/acre at midseason and when grown on clay soils the preflood N rate should be increased by 30 lb N/acre. CL152 and LaKast when grown on most silt loam soils should do best when 150 lb N/acre is applied in a two-way split application of 105 lb N/acre at preflood and 45 lb N/acre at midseason; and when grown on clay soils the preflood N rate should be increased by 30 lb N/acre to 135 lb N/acre.

INTRODUCTION

The Variety × Nitrogen (N) Fertilizer Rate Study measures the grain yield performance of the new rice varieties 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. Eight new rice varieties were entered and studied in 2013 at three locations as follows: LaKast is a new short stature, long-grain variety entered by Arkansas; Antonio and Colorado were entered by Texas and they both are long-grain, semidwarf varieties; Louisiana entered the new semidwarf, medium-grain variety Caffey, the aromatic, long-grain rice varieties Della2 and Jazzman2 and the semidwarf, long-grain Mermentau; and Horizon AG entered the Clearfield semidwarf, long-grain variety CL152 in cooperation with Louisiana. Clearfield rice varieties are tolerant to the broad spectrum herbicide imazethapyr (Newpath).

PROCEDURES

Locations at University of Arkansas System Division of Agriculture's centers/stations where the Variety × N Fertilizer Rate Study were conducted and corresponding soil series are as follows: Northeast Research and Extension Center (NEREC), Keiser, Ark., on a Sharkey clay (Vertic Haplaquepts); Pine Tree Research Station (PTRS), near Colt, Ark., on a Calloway silt loam (Glossaquic Fragiudalfs); and the Rice Research and Extension Center (RREC), near Stuttgart, Ark., on a DeWitt silt loam (Typic Albaqualfs). The experimental design utilized at all locations for all the rice varieties studied was a randomized complete block with four replications. A single preflood N fertilizer application was utilized for all varieties and was applied as urea on to a dry soil surface at 4- to 5-lf stage. The preflood N rates were: 0, 60, 90, 120, 150, 180, and 210 lb N/acre. The studies on the two silt loam soils at the PTRS and the RREC received the 0 to 180 lb N/acre fertilizer rates and the studies on the clay soil at the NEREC received the 0 to 210 lb N/acre N rates with the 60 lb N/acre rate omitted. The reasoning behind this is that rice usually requires about 30 to 60 lb N/acre more N fertilizer to maximize grain yield when grown on clay soils compared to the silt loams. All of the rice varieties were drill-seeded on the silt loams and clay soil at rates of 91 and 114 lb/acre, respectively, in plots 9 rows wide (row spacing of 7 inches), 15 ft. in length. Pertinent agronomic dates at each location in 2013 are shown in Table 1. The studies were flooded at each location when the rice was at the 4- to 5-lf stage and within 2 days of preflood N fertilization. The studies remained flooded until the rice was mature. At maturity, the center 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 (SAS Institute, Inc., Cary, N.C.) and mean separations were based upon Fisher's Protected Least Significant Difference test (*P* = 0.05) where appropriate.

RESULTS AND DISCUSSION

A single preflood N application method was adopted in 2008 in all Variety × 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 varieties reach a maximum yield with less N when the N is applied in a single preflood application compared to a two-way split. Typically, the rice varieties 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-inch 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. With the rising costs of N fertilizer, growers should consider the single, optimum preflood N application method. 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-inch flood depth is maintained for at least 3 weeks following flood establishment.

In most years, the silt loam soil at the RREC has the largest amount of plant-available N, followed by the silt loam soil at the PTRS and then the clay soil at the NEREC. Thus, most rice varieties require a lower N fertilizer rate to maximize grain yield at the RREC compared to at the PTRS or NEREC, and usually a little less at the PTRS than at the NEREC. Pertinent agronomic information such as planting, herbicide, fertilization, and flood dates are shown in Table 1. Grain yields in the 2013 Variety × Nitrogen studies were generally lower than those in 2012 due probably to the 25 to 40 day later planting in 2013. Cool, wet weather and muddy soil conditions caused us to have to delay planting until 29 May at the NEREC, 20 May at the PTRS, and 30 April at the RREC (Table 1). Surprisingly, rice grain yields in commercial fields in Arkansas in 2013 broke the record set in 2012. Lodging was not an issue for any of the varieties at any of the three locations in 2013.

Antonio did not significantly increase in yield above the 186 bu/acre achieved when 120 lb N/acre was applied preflood on the clay soil at the NEREC (Table 2). Antonio had a maximum grain yield of 191 bu/acre at the NEREC when 180 lb N/acre was applied preflood. Antonio reached maximum yields of 179 and 204 bu/acre on the silt loam soils at the PTRS and RREC, respectively, when 120 lb N/acre was applied preflood. Yields of Antonio did not significantly increase on the two silt loam soils when up to 180 lb N/acre was applied preflood. Antonio displayed good yield stability over a wide N fertilizer rate range at all three locations with no lodging. Results from 2012 (Norman et al., 2013) and 2013 indicate Antonio should require an N rate of 135 lb N/acre applied in a two-way split application of 90 lb N/acre at preflood and 45 lb N/acre at midseason to maximize grain yield on most silt loam soils, and when grown on clay soils the preflood N rate should be increased by 30 lb N/acre to 120 lb N/acre.

Caffey yielded over 200 bu/acre at all three locations in 2013 (Table 3), just like it did in 2012 (Norman et al., 2013). Caffey did not significantly increase in grain yield when more than 120 lb N/acre was applied preflood on the clay soil at the NEREC and reached a maximum yield of 236 bu/acre when 150 lb N/acre was applied preflood. Caffey maintained a stable grain yield of over 227 bu/acre with no lodging when 120 to 210 lb N/acre was applied at the NEREC. Caffey did not significantly increase in yield above the 200 bu/acre it obtained when 90 lb N/acre was applied preflood on the silt loam soil at the PTRS and maintained this grain yield when up to 180 lb N/acre was applied. Caffey obtained a grain yield of 232 bu/acre when only 60 lb N/acre was applied preflood on the silt loam soil at the RREC. Similar to the other locations, Caffey displayed good yield stability with no lodging when 60 to 180 lb N/acre was applied at the RREC. Results from 2011 (Norman et al., 2012), 2012 (Norman et al., 2013), and 2013 indicate Caffey should require an N rate of 135 lb N/acre applied in a two-way split application of 90 lb N/acre at preflood and 45 lb N/acre at midseason to maximize grain yield on most silt loam soils; and when grown on clay soils, the preflood N rate should be increased by 30 lb N/acre to 120 lb N/acre.

CL152 obtained a maximum grain yield of 175 bu/acre on the clay soil at NEREC when 150 lb N/acre was applied preflood and did not significantly increase or decrease in grain yield when up to 210 lb N/acre was applied (Table 4). A peak grain yield of 178 bu/acre was achieved by CL152 on the silt loam soil at PTRS when 180 lb N/acre was applied preflood. However, CL152 did not significantly increase in grain yield above the 177 bu/acre it achieved when only 90 lb N/acre was applied preflood. CL152 was able to maintain a stable, peak grain yield of 174 to 178 bu/acre when 90 to 180 lb N/acre was applied preflood at the PTRS. One of the strengths of CL152 we observed in 2013 and in past years (Norman et al., 2012, 2013) is its ability to maintain a stable, maximum grain yield over a wide range of N fertilizer rates with generally little to no lodging. CL152 achieved a maximum grain yield of 189 bu/acre on the silt loam soil at the RREC when 120 lb N/acre was applied preflood. However, CL152 did not significantly increase in grain yield over the 184 bu/acre it obtained when only 60 lb N/acre was applied preflood. A stable grain yield was maintained by CL152 at the RREC when 60 to 120 lb N/acre was applied preflood. When the N rate was increased to 150 and 180 lb N/acre, CL152 decreased to 174 and 169 bu/acre, respectively. After 3 years of study (Norman et al., 2012, 2013) it appears CL152 should do well with minimal lodging if 150 lb N/acre is applied in a two-way split of 105 lb N/acre 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 preflood and 45 lb N/acre at midseason when grown on clay soils.

Lodging was not a problem for Colorado in 2013 like it was in 2012 (Norman et al., 2013). Colorado did not significantly increase in yield on the clay soil at NEREC when more than 120 lb N/acre was applied preflood and maximized yield at 196 bu/acre when 150 lb N/acre was applied preflood (Table 5). A stable grain yield was exhibited by Colorado when 120 to 180 lb N/acre was applied preflood at the NEREC. Colorado obtained a maximum yield of 182 bu/acre on the silt loam soil at the PTRS when 150 lb N/acre was applied preflood and significantly decreased in yield to 169 bu/acre when the N rate was increased to 180 lb N/acre. However, Colorado did display a yield of 165 to 182 bu/acre when 60 to 180 lb N/acre was applied at the PTRS indicating a fairly stable grain yield over a wide range of N fertilizer rates. Colorado reached a peak grain yield of 196 bu/acre when 120 lb N/acre was applied to the silt loam soil at the RREC, but did not significantly increase in yield above the 188 bu/acre Colorado achieved when 90 lb N/acre was applied at the RREC. Colorado was able to maintain a stable grain yield at the RREC when 90 to 180 lb N/acre was applied preflood. After 2 years of study (Norman et al., 2013) it appears Colorado should do well when 135 to 150 lb N/acre is applied in a two-way split of 90 to 105 lb N/acre preflood and 45 lb N/acre at midseason when grown on silt loam soils and 165 to 180 lb N/acre in a two-way split of 120 to 135 lb N/acre preflood and 45 lb N/acre at midseason when grown on clay soils.

Della2 did not yield as well in 2013 as it did in 2012 (Norman et al., 2013). Della2 did not significantly increase in grain yield when more than 150 lb N/acre (155 bu/acre) was applied preflood on the clay soil at the NEREC and did not significantly decrease in yield when up to 210 lb N/acre was applied preflood (Table 6). Della2 had a similar yield of 152 to 156 bu/acre when 90 to 180 lb N/acre was applied preflood on the silt loam soil at the PTRS. Della2 achieved a maximum grain yield of 182 bu/acre on the silt loam soil at the RREC when 120 lb N/acre was applied preflood and did not significantly increase in grain yield when up to 180 lb N/acre was applied at the RREC. Della2 displayed good yield stability at the RREC and the other two locations over an N rate range of 90 lb N/acre. Results from 2012 (Norman et al., 2013) and 2013 indicate Della2 should require an N rate of 135 lb N/acre applied in a two-way split application of 90 lb N/acre at preflood and 45 lb N/acre at midseason to maximize grain yield on most silt loam soils and when grown on clay soils the preflood N rate should be increased by 30 lb N/acre to 120 lb N/acre.

Jazzman2 achieved a maximum grain yield of 171 bu/acre on the clay soil at the NEREC when 120 lb N/acre was applied preflood and did not significantly increased in yield when the N rate was increased (Table 7). Similarly, Jazzman2 obtained maximum grain yields of 177 bu/acre and 181 bu/acre when 120 lb N/acre was applied preflood to the silt loam soils at the PTRS and RREC, respectively. JazzMan2 did not significantly increase in yield when more than 120 and 90 lb N/acre was applied preflood at the PTRS and RREC, respectively. Jazzman2 showed good yield stability over a 60 to 90 lb N/acre N rate range without any lodging even when the N rate to achieve maximum yield was greatly surpassed. Results from 2011 (Norman et al., 2012), 2012 (Norman et al., 2013), and 2013 indicate Jazzman2 should require an N rate of 135 lb N/acre applied in a two-way split application of 90 lb N/acre at preflood and 45 lb N/acre at midseason to maximize grain yield on most silt loam soils and when grown on clay soils the preflood N rate should be increased by 30 lb N/acre to 120 lb N/acre.

LaKast reached a maximum grain yield of 215 bu/acre when 150 lb N/acre was applied preflood at the NEREC and did not significantly decrease in yield until 210 lb N/acre was applied preflood (Table 8). The yield of LaKast reached 208 bu/acre when 120 lb N/acre was applied preflood to the silt loam soil at the PTRS and did not significantly increase in yield when the N rate was increased above 120 lb N/acre. LaKast produced 215 bu/acre when only 60 lb N/acre was applied to the silt loam soil at the RREC and obtained a maximum yield of 245 bu/acre when 120 lb N/acre was applied at the RREC. LaKast did not significantly increase in yield when greater than 90 lb N/acre was applied at the RREC. LaKast displayed a stable grain yield at all three locations with no lodging when the N rate to maximize yield was exceeded by 60 to 90 lb N/acre. After 2 years of study (Norman et al., 2013) it appears LaKast, formerly termed RU0801081, should do well with minimal lodging if 150 lb N/acre is applied in a two-way split of 105 lb N/acre 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 preflood and 45 lb N/acre at midseason when grown on clay soils.

Mermentau obtained a maximum grain yield of 189 bu/acre when 150 lb N/acre was applied preflood to the clay soil at the NEREC (Table 9). Mermentau obtained a maximum grain yield of 175 bu/acre when 120 lb N/acre was applied preflood to the silt loam soil at the PTRS. Mermentau achieved a maximum grain yield of 208 bu/acre on the silt loam soil at the RREC when 90 lb N/acre was applied preflood. Mermentau had very stable grain yields over a wide range of N fertilizer rates at all three locations even when the N rate to maximize yield was exceeded by 60 lb N/acre. After 2 years of study (Norman et al., 2013) it appears Mermentau should yield well with minimum lodging when 135 to 150 lb N/acre is applied in a two-way split of 90 to 105 lb N/acre preflood and 45 lb N/acre at midseason when grown on silt loam soils and 165 to 180 lb N/acre in a two-way split of 120 to 135 lb N/acre preflood and 45 lb N/acre at midseason when grown on clay soils.

The Wells rice variety 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 varieties over the N fertilizer rates applied at the three locations (Table 10).

SIGNIFICANCE OF FINDINGS

The Variety × N Fertilizer Rate Study examines the grain yield performance of a new rice variety 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 determine the proper N fertilizer rate for a variety to achieve maximum grain yield when grown commercially in the Arkansas rice growing region. The eight rice varieties studied in 2013 were: Antonio, Caffey, Horizon Ag's CL152, Colorado, Della2, Jazzman2, LaKast, and Mermentau. The data generated from multiple years of testing of each variety will be used to determine the proper N fertilizer rate for a variety to achieve maximum yield when grown commercially on most silt loam and clay soils in Arkansas.

ACKNOWLEDGMENTS

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Table 1. Pertinent agronomic information for the Northeast Research and Extension Center (NEREC), Keiser, Ark., the Pine Tree Research Station (PTRS), near Colt, Ark., and the Rice Research and Extension Center (RREC), near Stuttgart, Ark., during 2013.

Practices	NEREC	PTRS	RREC
Preplant fertilizers 30 lb/acre $ZnSO_4$	100 lb/acre DAP	200 lb/acre 0-20-30	200 lb/acre 0-30-30 +
Planting date	28 May	20 May	16 April
Emergence date	9 June	30 May	30 April
Herbicide spray date and procedures	29 May 1.3 pt/acre Command + 40 oz/acre Facet L 1 gal/acre liquid Zinc	20 June 3 qt/acre RiceShot + 2 pts/acre Bolero +	17 April 20 oz/acre Obey
Herbicide spray date and procedures	29 June 4 qt/acre Propanil + 0.5 pt/acre Grandstand	2 July 3 qt/acre RiceShot + 1 oz/acre Permit	4 June 3 qt/acre RiceShot + 0.67 oz/acre Permit Plus
Preflood N date	1 July	24 June	14 June
Flood date	3 July	25 June	17 June
Harvest date	25 October	23 September	5 September

Table 2. Influence of nitrogen (N) fertilizer rate on the grain yield of Antonio rice at three locations during 2013.

	Grain yield		
N fertilizer rate	NEREC[a]	PTRS	RREC
(lb N/acre)	----------	(bu/acre)	----------
0	84	100	110
60	----	160	170
90	172	170	197
120	186	179	204
150	189	177	198
180	191	175	192
210	181	----	-----
LSD0.05	10.0	8.1	6.1

[a] NEREC = Northeast Research and Extension Center, Keiser, Ark.; PTRS = Pine Tree Research Station, near Colt, Ark.; RREC = Rice Research and Extension Center, Stuttgart, Ark.

Table 3. Influence of nitrogen (N) fertilizer rate on the grain yield of Caffey rice at three locations during 2013.

	Grain yield		
N fertilizer rate	NEREC[a]	PTRS	RREC
(lb N/acre)	----------	(bu/acre)	----------
0	110	94	159
60	----	167	215
90	192	200	232
120	228	202	218
150	236	194	217
180	235	194	212
210	227	----	-----
LSD0.05	8.4	10.2	8.7

[a] NEREC = Northeast Research and Extension Center, Keiser, Ark.; PTRS = Pine Tree Research Station, near Colt, Ark.; RREC = Rice Research and Extension Center, Stuttgart, Ark.

Table 4. Influence of nitrogen (N) fertilizer rate on the grain yield of CL152 rice at three locations during 2013.

	Grain yield		
N fertilizer rate	NEREC[a]	PTRS	RREC
(lb N/acre)	----------	(bu/acre)	----------
0	82	93	125
60	----	157	184
90	141	177	186
120	166	174	189
150	175	176	174
180	173	178	169
210	169	----	-----
LSD0.05	8.1	6.2	7.0

[a] NEREC = Northeast Research and Extension Center, Keiser, Ark.; PTRS = Pine Tree Research Station, near Colt, Ark.; RREC = Rice Research and Extension Center, Stuttgart, Ark.

Table 5. Influence of nitrogen (N) fertilizer rate on the grain yield of Colorado rice at three locations during 2013.

	Grain yield		
N fertilizer rate	NEREC[a]	PTRS	RREC
(lb N/acre)	----------------------------	(bu/acre)	--------------------------
0	96	104	109
60	----	165	163
90	162	165	188
120	187	173	196
150	196	182	194
180	189	169	191
210	170	----	-----
LSD0.05	10.4	6.5	8.3

[a] NEREC = Northeast Research and Extension Center, Keiser, Ark.; PTRS = Pine Tree Research Station, near Colt, Ark.; RREC = Rice Research and Extension Center, Stuttgart, Ark.

Table 6. Influence of nitrogen (N) fertilizer rate on the grain yield of Della2 rice at three locations during 2013.

	Grain yield		
N fertilizer rate	NEREC[a]	PTRS	RREC
(lb N/acre)	----------------------------	(bu/acre)	--------------------------
0	65	97	120
60	----	145	156
90	136	152	171
120	147	156	182
150	155	153	175
180	157	156	171
210	153	----	-----
LSD0.05	4.3	11.1	8.2

[a] NEREC = Northeast Research and Extension Center, Keiser, Ark.; PTRS = Pine Tree Research Station, near Colt, Ark.; RREC = Rice Research and Extension Center, Stuttgart, Ark.

Table 7. Influence of nitrogen (N) fertilizer rate on the grain yield of Jazzman2 rice at three locations during 2013.

	Grain yield		
N fertilizer rate	NEREC[a]	PTRS	RREC
(lb N/acre)	----------------------------	(bu/acre)	--------------------------
0	89	86	98
60	----	147	167
90	160	165	179
120	171	177	181
150	169	170	181
180	171	172	178
210	157	----	-----
LSD0.05	8.2	7.3	8.0

[a] NEREC = Northeast Research and Extension Center, Keiser, Ark.; PTRS = Pine Tree Research Station, near Colt, Ark.; RREC = Rice Research and Extension Center, Stuttgart, Ark.

Table 8. Influence of nitrogen (N) fertilizer rate on the grain yield of LaKast rice at three locations during 2013.

	Grain yield		
N fertilizer rate	NEREC[a]	PTRS	RREC
(lb N/acre)	----------	(bu/acre)	----------
0	104	88	136
60	----	153	215
90	191	194	239
120	202	208	245
150	215	197	241
180	215	200	229
210	199	----	-----
LSD0.05	10.5	8.5	10.3

[a] NEREC = Northeast Research and Extension Center, Keiser, Ark.; PTRS = Pine Tree Research Station, near Colt, Ark.; RREC = Rice Research and Extension Center, Stuttgart, Ark.

Table 9. Influence of nitrogen (N) fertilizer rate on the grain yield of Mermentau rice at three locations during 2013.

	Grain yield		
N fertilizer rate	NEREC[a]	PTRS	RREC
(lb N/acre)	----------	(bu/acre)	----------
0	82	89	127
60	----	155	191
90	176	166	208
120	179	175	207
150	189	168	198
180	187	169	192
210	184	----	-----
LSD0.05	5.1	7.1	7.2

[a] NEREC = Northeast Research and Extension Center, Keiser, Ark.; PTRS = Pine Tree Research Station, near Colt, Ark.; RREC = Rice Research and Extension Center, Stuttgart, Ark.

Table 10. Influence of nitrogen (N) fertilizer rate on the grain yield of Wells rice at three locations during 2013.

	Grain yield		
N fertilizer rate	NEREC[a]	PTRS	RREC
(lb N/acre)	----------	(bu/acre)	----------
0	85	97	108
60	-----	154	178
90	173	177	195
120	191	187	217
150	203	186	211
180	208	180	202
210	203	-----	-----
LSD0.05	6.7	10.9	11.9

[a] NEREC = Northeast Research and Extension Center, Keiser, Ark.; PTRS = Pine Tree Research Station, near Colt, Ark.; RREC = Rice Research and Extension Center, Stuttgart, Ark.

RICE CULTURE

Response of Two Rice Varieties to Midseason Nitrogen Fertilizer Application Timing

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ABSTRACT

A study was conducted at three locations in 2013 to examine the influence of midseason nitrogen (N) application and its timing on the grain yield of conventional, pure-line rice (*Oryza sativa* L.) varieties from Louisiana and Arkansas. The conventional rice varieties chosen for the study at the University of Arkansas System Division of Agriculture Northeast Research and Extension Center (NEREC), Pine Tree Research Station (PTRS), and Rice Research and Extension Center (RREC) were the Louisiana semidwarf, long-grain CL152 and the Arkansas short stature, long-grain Roy J. There were two preflood N rates and four midseason N application timings at beginning internode elongation (BIE), BIE+7 days, BIE+14 days, and BIE+21 days. There was also a check or no midseason N application and a single preflood N application. Roy J produced a greater yield than CL152 at the NEREC and RREC and CL152 out yielded Roy J at the PTRS. A single preflood N application produced a similar or greater yield than the two-way split application. Application of midseason N generally increased grain yield when applied at all of the application times at both preflood N rates at the NEREC and RREC, but not at the PTRS at the higher preflood N rate were there was no response. The midseason N application window appeared to be 2 to 3 weeks wide with a tendency at times for grain yield to increase as the midseason N was delayed. This tendency could be due to the short time span (i.e., 2 weeks) between when the preflood N was applied and the rice reaching BIE causing the BIE and BIE+7 days midseason N applications being applied when the rice was still possibly taking up the preflood N. This might have reduced the uptake and/or the impact on grain yield of these early midseason N applications.

INTRODUCTION

Nitrogen fertilizer is applied to dry-seeded, delayed-flood rice in two-split applications for conventional, pure-line rice varieties (Norman et al., 2013b). The first N application is applied onto dry soil, preflood, at beginning tillering and the second N application is applied into the floodwater at midseason between BIE and BIE+7 days or ~0.5-inch IE (Norman et al., 2013b). The preflood N application is the larger of the two and ranges from 75 to 105 lb N/acre, depending on the variety (Roberts and Hardke, 2013). The midseason N application is 45 lb N/acre for all conventional rice varieties. It has been over 15 years since the recommendation for midseason N application to rice was updated to indicate midseason N could be applied from BIE to 0.5-inch IE (Wilson et al., 1998). Because of the introduction of new varieties since the last midseason N timing study was conducted, it was thought a new study should be conducted to determine how the recently released varieties respond to midseason N application and timing.

Recent research has indicated the new varieties do not always respond to midseason N, especially if an adequate rate of preflood N has been applied. Additionally, the results indicated when there is a response to midseason N the application time window may be wider than a week and/or later than 0.5-inch IE. The 2010 results showed rice grain yield increased for Cheniere and Taggart when the midseason N application was delayed from 0.5-inch IE until 0.5-inch IE+7 or 14 days, but not when it was delayed from 0.5-inch IE+7 days until 0.5-inch IE+14 days, and the 2011 results indicated the midseason N could be applied from BIE to BIE+14 days and have a positive influence on rice grain yield (Norman et al., 2012). The 2012 results showed application of midseason N had no influence on rice grain yield at one location; whereas, at the other two locations, midseason N applied from BIE to BIE+21 days significantly increased rice grain yield (Norman et al., 2013a). Consequently, the midseason N application timing study was continued in 2013 to determine the grain yield response of rice to midseason N applied at four times from BIE to BIE+21 days when two rates of N fertilizer were applied preflood. The two conventional, pure-line rice varieties chosen for the 2013 study were the semidwarf, long-grain variety CL152 from Louisiana and the short stature, long-grain Roy J from Arkansas.

PROCEDURES

The study was conducted in 2013 at the University of Arkansas System Division of Agriculture PTRS, near Colt, Ark., on a Calhoun silt loam, the RREC, near Stuttgart, Ark., on a DeWitt silt loam, and the NEREC, Keiser, Ark., on a Sharkey clay. The two conventional rice varieties chosen for the study were the Louisiana long-grain, semidwarf CL152 and the Arkansas long-grain, short stature Roy J. Two preflood N rates of 45 and 90 lb N/acre were utilized along with four midseason N application timings. The midseason N rate was 45 lb N/acre and was applied at BIE, BIE+7 days BIE+14 days, and BIE+21 days. There was a check or no midseason N application and a single preflood N application of 120 lb N/acre at the PTRS and RREC and a 150 lb N/acre single preflood N application at NEREC, both replicated four times. The preflood N was applied onto dry soil just prior to flooding and the midseason N was applied directly into the floodwater.

The rice was drill-seeded at a rate of 91 lb/acre on the silt loam soils at the PTRS and RREC and 114 lb/acre on the clay soil at the NEREC, in plots 9 rows wide (row spacing of 7 inches), 15 ft in length. The rice was seeded at the PTRS on 20 May, emerged 30 May, the preflood N applied 24 June, and the BIE application was applied on 11 July; the rice was seeded at the RREC on 8 May, emerged 17 May, the preflood N applied 26 June, and the BIE N application was applied on 10 July; and the rice was seeded at the NEREC on 28 May, emerged 9 June, the preflood N applied 1 July, and the BIE N application was applied on 16 July. The permanent flood was established the day after the preflood N was applied at all locations when the rice was at the 5- to 7-lf stage and the flood maintained 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).

The treatments were arranged as a randomized complete block, 2 (variety) × 2 (preflood N rate) × 4 (midseason N application time), factorial design with four replications, a no midseason N application (control) with four replications, and a single preflood N application with four replications was included at all locations. Analysis of variance was performed on the grain yield data utilizing SAS v. 9.1 (SAS Institute, Cary, N.C.). Differences among means were compared using Fisher's Protected Least Significant Difference (LSD) procedure at a $P = 0.05$ probability level.

RESULTS AND DISCUSSION

Analysis of variance *P* values for the studies indicated there was no significant ($P = 0.05$) three-way interactions of variety × preflood N rate × midseason N timing on rice grain yield at any of the three locations (Table 1). However, there were significant two-way interactions on rice grain yield of preflood N rate × midseason N timing at the NEREC ($P = 0.0295$) and PTRS ($P = 0.0247$), variety × midseason N timing at the NEREC ($P = 0.0383$), and variety × preflood N rate at the NEREC ($P < 0.0001$) and PTRS ($P = 0.0004$). Although there were no significant two-way interactions on rice grain yield at the RREC there were main effects of variety ($P < 0.0001$), preflood N rate ($P < 0.0001$), and midseason N application timing ($P = 0.0017$) on rice grain yield.

At the RREC, there were no interactions just main effects of variety, preflood N rate, and midseason N timing influenced rice grain yields (Table 1). Roy J out yielded CL152 by over 20 bu/acre at the RREC (Table 2). Grain yield increased with the two-way split application when the preflood N rate was increased from 45 to 90 lb N/acre at the RREC (Table 3). A single preflood N application produced a similar yield to the two-way split application when 90 lb N/acre was applied preflood and both produced a greater yield than the two-way split application when 45 lb N/acre was applied preflood. Application of midseason N increased grain yield when applied at all of the application times at the RREC, except when applied at BIE+7 days (Table 4); error or anomaly? The single preflood N application resulted in a greater yield than the two-way split application when the midseason N was applied at BIE and BIE+7 days, but not when applied at BIE+14 days or BIE+21days.

The variety and preflood N rate interaction, averaged over midseason N timing, on rice grain yield at the NEREC and PTRS showed the grain yield increased for both varieties when the preflood N rate of the two-way split was increased from 45 to 90 lb N/acre (Table 5). Roy J produced a greater yield than CL152 at both preflood rates of the two-way split application and when N was applied in a single preflood application at the NEREC. Interestingly, CL152 produced a greater yield than Roy J at both preflood rates of the two-way split application and when the N was applied in a single preflood application at the PTRS. Both varieties produced a greater yield with the single preflood N application compared to the two-way split application at both preflood N rates at the NEREC, but the single preflood N rate was mistakenly applied at a 15 lb N/acre greater rate than the two-way split at the NEREC. The single preflood N rate at the PTRS and RREC was correctly applied at a 15 lb N/acre lesser rate than the two-way split. At the PTRS, Roy J produced a greater yield and CL152 a similar yield with the single preflood N application compared to with the two-way split application when 90 lb N/acre was applied preflood. Both varieties of course produced a greater yield with the single preflood N application compared to with the two-way split application when 45 lb N/acre was applied preflood at the PTRS.

Both varieties produced a greater yield when midseason N was applied at the NEREC, regardless of midseason N application time (Table 6). Clearfield 152 yielded similarly when the midseason N was applied all four application times, the only exception was a greater yield when the midseason N was applied at BIE+7 days compared to at BIE. Roy J yielded better when the midseason N was applied later than BIE and then appeared to show an increase when it was delayed from BIE+14 days to BIE+21 days. Both varieties produced a greater yield with the larger single preflood N application compared to the two-way split application at the NEREC, regardless of midseason N application time.

All midseason N application times increased grain yield at both preflood N rates at the NEREC (Table 7). All midseason N application times increased yield similarly at the lower preflood N rate at this location, but not at the higher preflood N rate. At the higher preflood N rate at NEREC, midseason N increased yield when delayed from BIE to the later application times, but the increase was erratic. The grain yield was similar when comparing the midseason N application at BIE+7days to at BIE+14 and 21 days; however, there was a significant increase when delayed from BIE+14 days to BIE+21 days at the NEREC. It could be the grain yield when midseason N was applied at BIE+14 days is artificially low, just an error or anomaly. At the PTRS, midseason N applied at BIE did not increase grain yield at the lower preflood N rate, but all of the later midseason N application times did increase yield compared to when no midseason was applied or applied at BIE. At the higher preflood N rate, midseason N did not increase yield regardless of application time at the PTRS.

SIGNIFICANCE OF FINDINGS

Generally, application of midseason N increased grain yield at all three locations and at both preflood N rates, except at the PTRS at the higher preflood N rate. Also, all midseason application times generally increased rice grain yield with a trend for grain yields to increase as midseason application time was delayed. This indicates the midseason N application window is wider than previously thought. Beginning internode elongation was reached at all three locations only about 2 weeks after the preflood N was applied. Delayed flood rice typically requires 3 weeks to achieve maximum uptake of the preflood N. Consequently, the BIE, and possibly the BIE+7 days, midseason N application was probably applied while the rice was still taking up the preflood N application and this might have reduced the uptake and/or the impact on grain yield of these early midseason N applications. This would also explain the tendency for rice grain yield to increase as the midseason N application was delayed. A single preflood N application resulted in similar or greater grain yields than when N was applied in two split applications.

ACKNOWLEDGMENTS

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Table 1. Analysis of variance *P* values for rice grain yield as affected by rice variety, preflood N rate, and midseason N timing at the Northeast Research and Extension Center (NEREC), Pine Tree Research Station (PTRS), and Rice Research and Extension Center (RREC) during 2013.

Source	NEREC	PTRS	RREC
Variety (Var)	<0.0001	<0.0001	<0.0001
Preflood N Rate (Pfn)	<0.0001	<0.0001	<0.0001
Midseason N timing (msn timing)	<0.0001	0.0004	0.0017
Var × pfn rate	<0.0001	0.0004	0.1545
Var × msn timing	0.0383	0.7873	0.4357
Pfn rate × msn timing	0.0295	0.0247	0.2080
Var × pfn × msn timing	0.8919	0.3693	0.3148

Table 2. Influence of rice variety, averaged over preflood N rate and midseason N timing, on rice grain yield at the Rice Research and Extension Center during 2013.

Variety	Grain yield
	(bu/acre)
CL152	188
Roy J	210
$LSD_{0.05}$	3.4

Table 3. Influence of preflood N rate, averaged over midseason N timing and variety, on rice grain yield at the Rice Research and Extension Center during 2013.

Preflood N rate	Grain yield
(lb N/acre)	(bu/acre)
45[a]	195
90[a]	202
120[b]	206
$LSD_{0.05}$	5.5

[a] 45 lb N/acre applied at midseason.

[b] Single preflood N fertilizer application with no midseason.

Table 4. Influence of midseason (MS) N application timing, averaged over preflood N rate and variety, on rice grain yield at the Rice Research and Extension Center during 2013.

MS N timing	Grain yield
	(bu/acre)
No MS N	192
BIE[a]	199
BIE+7 days	196
BIE+14 days	201
BIE+21 days	204
SPF[b]	206
$LSD_{0.05}$	6.1

[a] BIE = beginning internode elongation.

[b] SPF = single preflood N fertilizer application of 120 lb N/acre with no midseason N.

Table 5. Influence of the variety and preflood N rate interaction, averaged over midseason N timing, on rice grain yield at the Northeast Research and Extension Center (NEREC) and the Pine Tree Research Station (PTRS) during 2013.

	Grain yield			
	NEREC		PTRS	
Preflood N rate	CL152	Roy J	CL152	Roy J
(lb N/acre)	(bu/acre)			
45[a]	145	162	171	145
90[a]	175	207	190	175
120[b]	---	---	193	185
150[b]	181	225	---	---
$LSD_{0.05}$	5.9		4.3	

[a] 45 lb N/acre applied at midseason.

[b] Single preflood N fertilizer application with no midseason.

Table 6. Influence of the variety and midseason (MS) N application timing interaction, average over preflood N rate, on rice grain yield at the Northeast Research and Extension Center during 2013.

	Grain yield	
MS N timing	CL152	Roy J
	----------- (bu/acre)-----------	
No MS N	144	161
BIE[a]	158	178
BIE+7 days	168	192
BIE+14 days	163	191
BIE+21 days	166	200
SPF[b]	181	225
$LSD_{0.05}$	8.1	

[a] BIE = beginning internode elongation.

[b] SPF = single preflood N fertilizer application of 150 N/acre with no midseason N.

Table 7. Influence of preflood (PF) N rate and midseason (MS) N application timing interaction, average over varieties, on rice grain yield at the Northeast Research and Extension Center (NEREC) and the Pine Tree Research Station (PTRS) during 2013.

	Location/PF N rate			
	NEREC		PTRS	
MS N timing	45	90	45	90
	---------------------- [Grain yield (bu/acre)] ----------------------			
No MS N	139	170	149	179
BIE[a]	155	184	152	183
BIE+7 days	158	203	162	181
BIE+14 days	157	196	163	185
BIE+21 days	162	208	163	182
SPF[b]	206		189	
$LSD_{0.05}$	9.1		6.7	

[a] BIE = beginning internode elongation.

[b] SPF = single preflood fertilizer application of 150 lb N/acre at NEREC and 120 lb N/acre at PTRS.

Field Validation of the Nitrogen Soil Test for Rice (N-ST*R) for Rice Produced on Clay Soils

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ABSTRACT

To facilitate the development and incorporation of the Nitrogen (N) Soil Test for Rice (N-ST*R), field validation studies were established on clay soils across the state of Arkansas at University of Arkansas System Division of Agriculture experiment stations as well as in a producer field. Prior to flooding, 12 inch soil samples were taken and analyzed by N-ST*R. These field trials compared N rates from three calibration curves developed to predict 90%, 95%, and 100% relative grain yield (RGY), to the standard recommendation for rice grown on clay soils of 180 lb N/acre. Nitrogen fertilizer rates predicted from the three calibration curves ranged from 50 to 225 lb N/acre. Results from the replicated small-plot validation studies indicated that the N rates from the 95% RGY curves were never statistically different than the standard recommendation. Yield results from the 90% RGY treatments were significantly lower and were generally 90% of the maximum yield for a given location. Comparison of rice aesthetics within a field trial highlighted significant differences in rice height and color, with little to no difference in rice yield. These results indicate the importance of field-scale demonstration trials of the N-ST*R technology to educate producers, consultants, and extension personnel to help facilitate the widespread use of this new technology on clay soils.

INTRODUCTION

Current N fertilizer recommendations are based on a combination of three factors: soil texture, cultivar, and previous crop. To improve N fertilizer management for Arkansas rice producers, a stronger emphasis should be placed on the soil's ability to supply N. University of Arkansas researchers have developed the first soil-based N test for rice produced on silt loam and clay soils and have called it N-ST*R, the N Soil Test for Rice. The basis of this technology is to estimate the amount of N that the soil can supply during the growing season and adjust N fertilizer rates to maximize rice yield. The successful correlation and calibration of a soil-based N test has been the focal point of soil fertility research for many years and was first attempted by Wilson et al. (1994), who were unable to predict N needs for rice in a field setting. Roberts et al. (2011) was successful in correlating and calibrating a direct steam distillation method (DSD) that was highly correlated with rice total N uptake as well as percent relative grain yield (RGY). Fulford et al. (2013) indicated that N-ST*R was highly correlated with rice response parameters and that N rate calibrations could be effectively made for clay soils when sampled to a depth of 12 inches. Implementation of N-ST*R to predict site-specific N rates is becoming more and more important and will be essential for the long-term sustainability of Arkansas rice production. The benefits of N-ST*R are not just about optimizing economic or agronomic returns, but making environmentally sound N fertilizer decisions. The objective of this study is to evaluate and validate the ability of N-ST*R to predict site-specific N rates required to maximize rice yield on clay soils in Arkansas.

METHODS AND MATERIALS

Field experiments were conducted in Arkansas during the 2013 growing season on several clay soils around the state to evaluate the ability of N-ST*R to predict N fertilizer needs for rice. Studies were conducted at the University of Arkansas System Division of Agriculture Northeast Research and Extension Center (NEREC) near Keiser, Ark.; Rohwer Research Station (RRS) near Rohwer, Ark.; and in a producer field (Prod-13) with cultivars that had similar N fertilizer requirements. On the research centers, rice was seeded at ~85 lb/acre in 9 row plots (7 inch spacing) of 16 ft in length. The rice was grown upland until the 4- to 5-lf growth stage at which time a permanent flood (2- to 4-inch depth) was established and maintained until maturity. The N-ST*R validation trials were randomized complete block designs with four replications and treatments that included a check (0 lb N/acre), N rates from the 90%, 95%, and 100% RGY N-ST*R calibration curves and the standard N recommendation for rice grown on clay soils (180 lb N/acre). For each of the plots receiving N, the majority was applied prior to flooding with 45 lb N/acre applied at midseason, unless the total predicted N rate was less than 75 lb N/acre and then the total N rate was applied in a single preflood application. Four 12-inch soil cores were taken prior to flooding from the entire plot area and analyzed by N-ST*R. Following maturity, the center four rows of each plot were harvested, the moisture content and weight of the grain were determined, and yields were calculated as bushel (bu)/acre at 12% moisture. A bushel of rice weighs 45 pounds. Treatments were compared within a site and means were separated using Fishers Protected Least Significant Difference test at $P = 0.05$ level. All statistical analyses were carried out using JMP v. 11.0 (SAS Institute, Inc., Cary, N.C.).

RESULTS AND DISCUSSION

Rice producers in Arkansas apply a wide range of N fertilizer rates and at varying application times (preflood, midseason etc.). Current N fertilizer recommendations suggest that for the majority of cultivars grown in Arkansas, a top yield can be achieved by applying 180 lb N/acre when produced on clay soils. This number is achieved statistically using the mean N rate to achieve maximum yield over several locations around the state and is referred to as Variety × Nitrogen (N) Fertilizer Rate Study. Possible problems associated with this approach are the differences in native soil N release from site to site or field to field. Unfortunately, not all producer fields are going to mimic the N mineralization potential that is seen within fertilizer rate trials held on experiment stations. To combat rising N fertilizer prices and eliminate potential environmental impacts from excessive N fertilizer application a soil-based N test, N-ST*R, was evaluated in production fields and on experiment stations across the state of Arkansas.

During the development of N-ST*R, three calibration curves were built to represent the N rates required to achieve 90%, 95%, and 100% RGY. Relative grain yield was chosen to represent the rice response parameter as rice yield can be influenced by many factors other than N rate including cultivar, environment, planting date and availability of other nutrients. Percent RGY was also chosen because maximum yield for Arkansas rice production often represents the most economical yield due to the price ratio of rough rice and N fertilizer as well as the input costs associated with direct-seeded, delayed-flood rice production. Predicted N rates obtained using N-ST*R ranged from 50 to 225 lb N/acre (Table 1) and represented a wide range of soil series and previous crops. Four of the five sites utilized in the study resulted in N-ST*R 95% RGY rate recommendations that were lower than the standard recommendation of 180 lb N/acre.

For the NEREC and RRS locations, two sites were identified that had significantly different levels of native soil N and therefore resulted in significantly different N-ST*R N rates (Table 1). The NEREC-1 site was located in an area with a traditional rice-soybean rotation whereas the NEREC-2 location had been in long-term soybean production. This difference in crop rotation attributed to the differences in N rate recommendations, with NEREC-2 requiring 25 lb N/acre less than NEREC-1 for each N-ST*R calibration curve. Differences in native N availability are also reflected in the check plot grain yield, where no N fertilizer was applied. Higher native N at NEREC-2 had a higher check plot grain yield compared to NEREC-1 indicating more N availability at NEREC-2. Although both NEREC locations had N-ST*R predicted N rates for all calibration curves that were less than the standard N rate recommendation, they produced statistically similar yields with less N fertilizer inputs than the standard recommendation. Yields obtained at NEREC-2 for the 90%, 95%, and 100% RGY calibration curves were all statistically equal to the yield obtained with the 180 lb N/acre rate, but required anywhere from 90 to 35 lb N/acre less. Similar trends were seen for NEREC-1, but the magnitude of N rate differences was much smaller and ranged from 65 to 10 lb N/acre less than the standard recommendation of 180 lb N/acre. Interestingly, the same yield of 213 bu/acre was obtained when the standard N recommendation of 180 lb N/acre was applied and when 115 lb N/acre was applied according to the 90% RGY calibration curve of

N-ST*R. This indicates how the use of N-ST*R can result in a significant N rate savings while maintaining yield potential.

Yields obtained at the RRS location resulted in different trends than were seen at the NEREC location (Table 1). Native N fertility at the RRS location tended to be lower than at NEREC and in some cases N-ST*R recommended more N than the standard recommendation of 180 lb N/acre. At RRS-1, the 95% and 100% RGY calibration curves indicated that more N was needed to produce maximal yields. Nitrogen rate predictions were 195 and 225 lb N/acre for the N-ST*R 95% and 100% RGY calibration curves, respectively. Although the N rate for the N-ST*R 95% RGY curve was higher, it did not result in a higher yield than the standard N rate. This implies the N-ST*R 95% RGY calibration curve for clay soils should be capped at around 180 lb N/acre; the soil at this site will be reevaluated to be certain this site was sampled and analyzed correctly. Soil N availability at RRS-2 was slightly higher than at RRS-1 and N-ST*R worked liked it usually does. The 208 bu/acre yield obtained with 165 lb N/acre according to the 95% RGY calibration curve was the same as the yield obtained with the standard recommendation of 180 lb N/acre.

During 2013, one validation trial was conducted in a producer field (Prod-13) that indicated very high levels of soil N availability (Table 1). This N-ST*R N rate prediction indicated that maximal yields could be obtained with as little as 75 lb N/acre at site Prod-13. Yield results indicated that there was no significant difference between the 95% and 100% RGY N rates, but that both of the yields obtained with these calibration curves were statistically higher than the yields obtained from both the standard recommendation and the 90% RGY N rate prediction. In this case it appears that rice yields were actually reduced when the standard N rate of 180 lb N/acre was applied versus when the N-ST*R rate of 75 lb N/acre was applied. The results presented from Prod-13 suggest that native soil N availability on clay soils may be more variable than once thought and that N-ST*R N savings could be greater for clay soils than for silt loam soils.

The N-ST*R is an exciting new technology that has the ability to revolutionize Arkansas rice production for rice produced on all soil textures. In order to facilitate the implementation and acceptance of this new technology on clay soils more work is needed on field-scale strip trials to educate people on what N-ST*R is and demonstrate its abilities on a large scale. This does not mean that yields cannot be lowered due to poor management of water or weeds, N fertilizer losses from ammonia volatilization or inadequate nutrients such as phosphorous and potash. The N rates predicted using N-ST*R are site-specific, prescription rates that assume minimal N fertilizer losses due to poor preflood N management and a urease inhibitor such as n-butyl thiophosphoric triamide (NBPT; trade names Agrotain, Arborite, Factor, and N-FIXX) should be used with urea and a flood established in a timely manner and maintained.

SIGNIFICANCE OF FINDINGS

The results obtained from this research indicate the ability of N-ST*R to accurately predict the N rate recommendation required to maximize yields for rice produced on clay soils in Arkansas. The results also revealed a site where N-ST*R gave an atypical, inaccurately high prediction implying the N-ST*R 95% RGY calibration curve for clay soils should be capped at around 180 lb N/acre; the soil at this site will be reevaluated to be certain this site was sampled and analyzed correctly. The sites utilized in this study represent a wide range of native soil N levels and indicate that there is a significant amount of variability in N-ST*R values across the state. The majority of these sites were located on experiment stations with different crop rotations, but the differences in yield maximizing N rates within a location, such as NEREC indicate that even slight changes in crop rotation over time can lead to significant differences in native soil N. These results also support the N rate recommendations provided by the N-ST*R lab in 2013 indicating that there is more opportunity for N rate savings on clay soils than on silt loam soils.

ACKNOWLEDGMENTS

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Table 1. Comparison of N-ST*R fertilizer N rate recommendations and the corresponding rice grain yield for five sites utilized in 2013.

	NEREC-1[†]		NEREC-2		RRS-1		RRS-2		Prod-13	
Treatment	N rate	Yield	N rate	Yield	N rate	Yield	N rate	Yield	N rate	Yield
	(lb N/acre)	(bu/acre)	(lb N/acre)	(bu/acre)	(lb N/acre)	(bu/acre)	(lb N/acre)	(bu/acre)	(lb N/acre)	(bu/acre)
Check	0	86 b	0	123 b	0	96 c	0	115 c	0	145 c
90% RGY	115	213 a	90	211 a	165	180 b	135	190 b	50	190 b
95% RGY	140	220 a	115	223 a	195	200 a	165	208 a	75	212 a
100% RGY	170	218 a	145	218 a	225	185 b	195	206 a	105	210 a
Std. Rec.	180	213 a	180	220 a	180	201 a	180	208 a	180	192 b

[†] NEREC = Northeast Research and Extension Center; RRS = Rohwer Research Station; and Prod-13= Producer field.

Rice Grain Yield As Influenced By Nitrogen Source, Rate, and Application Time

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ABSTRACT

Nitrogen (N) as urea is the most commonly applied fertilizer source in direct-seeded, delayed-flood rice production in Arkansas. Due to the alkaline and ammonium forming nature of urea hydrolysis, urea fertilizer is susceptible to N loss via ammonia (NH_3) volatilization to the atmosphere if a flood is not established in a timely manner. To minimize this loss mechanism, producers often utilize the urease inhibitor N-(n-butyl) thiophosphorictriamide (NBPT) to delay hydrolysis and thus, losses of urea as NH_3. The objectives of this study were to compare plant N uptake and rice grain yield of untreated urea to urea coated with NBPT. The study was conducted at the University of Arkansas System Division of Agriculture Pine Tree Research Station on a silt loam soil. The study investigated 2 N sources, 3 application timings (10, 5, and 1 day prior to flooding), and 2 N application rates (120 and 60 lb N/acre). Grain yield was greater from urea + NBPT compared to untreated urea on 5 and 10 days prior to flooding (DPF), but did not differ when applied 1 DPF. In addition, N uptake was greater from the 120 lb N/acre rate from urea + NBPT as compared to untreated urea; but at the 60 lb N/acre rate, no differences were measured. This research indicates that urea + NBPT can be beneficial when ≥5 days are required to flood a field.

INTRODUCTION

Nitrogen (N) fertilizer must be applied in the proper amounts and times to produce maximum agronomic rice (*Oryza sativa* L.) yield. Currently, the most efficient method of N fertilization for rice grown in the direct-seeded, delayed-flood production system is to apply an ammonium or ammonium-forming N source (e.g., urea) to a dry soil surface near the 5-lf stage of rice growth and incorporate the N quickly by establishing a flood that will be maintained for the duration of the growing season (Norman et al., 2013). Norman et al. (2003) reported that rice recovery of properly managed preflood urea-N was 60% to 75% of the total applied N. A second application of N fertilizer (~45 lb N/acre as urea) is generally applied into the floodwater near the panicle differentiation (PD) stage 3 to 4 wk after the preflood N application; however if sufficient N fertilizer is applied preflood, there is no need for the second N application at midseason. Following the recommended N fertilization guidelines allows for high yields, minimizes environmental N losses, and represents the most cost-efficient means for N fertilization of flood-irrigated rice.

Urea and ammonium sulfate are the N fertilizers recommended for preflood fertilization of rice in Arkansas (Norman et al., 2013); however, urea is the most commonly used N fertilizer for rice due to its high N analysis and relatively low cost. One major disadvantage of surface application of urea N is the potential for substantial N loss via ammonia (NH_3) volatilization (Norman et al., 2009), which is one of the two most prevalent N loss mechanisms in the drill-seeded, delayed-flood production system, with the other being denitrification of soil- or fertilizer-N that has undergone nitrification.

Griggs et al. (2007) reported NH_3 volatilization losses ranged from 20% to 30% of the total urea-N applied to a silt-loam soil 14 days before flooding. Ammonia volatilization losses from $(NH_4)_2SO_4$ were lower (<5%) compared with urea. The results of Griggs et al. (2007) indicated that a significant proportion of N applied as urea can be lost via NH_3 volatilization from silt-loam soils if the flood is not applied in a timely manner. Our research objectives were to: i) measure the NH_3 volatilization of urea with and without the urease inhibitor N-(n-butyl) thiophosphorictriamide (NBPT) (urea + NBPT) and ii) describe the differences in plant N uptake and rice grain yield as affected by N rate and application timing of fertilizer. The ultimate goal of these experiments was to determine if urea + NBPT would increase rice grain yield by effectively limiting NH_3 volatilization compared to untreated urea when applied several days in advance of the permanent flood.

PROCEDURES

Site Description

Research was established in 2013 to evaluate the influence of product and time of N application on rice grain yield and N uptake. Experiments were established at the University of Arkansas System Division of Agriculture Pine Tree Research Station (PTRS) on a Calloway silt loam (fine, smectitic, thermic, Glossaquic Natraudalfs) where soybean [*Glycine max* (L.) Merr.] was the previous crop grown in rotation.

Four composite soil samples were collected at PTRS before N-fertilizer application. Each composite sample consisted of 8, 1-inch diameter cores. Soil samples were oven-dried, crushed to pass through a 2-mm sieve, extracted using the Mehlich-3 method, and extracts were analyzed using inductively coupled plasma atomic emission spectroscopy.

Soil water pH was determined in a 1:2 soil weight:water volume ratio using a glass electrode. The mean values of selected soil chemical properties are listed in Table 1.

Treatments

Individual plots, measuring 6.5-ft wide × 16-ft long, were flagged to establish plot boundaries at both locations. The long-grain rice cultivar Wells was drill-seeded into conventionally tilled seedbeds at 80 lb seed/acre. Each plot contained 9 rows of rice spaced 7 inches apart and was surrounded by a 1.5-ft wide alley that contained no rice. Untreated urea and urea + NBPT (i.e., Agrotain) were applied at rates equivalent to 60 and 120 lb N/acre. Both N sources were applied at three timings: 1, 5, and 10 days prior to flooding (DPF). Following the 1 DPF N application, a 4-inch deep permanent flood was established and maintained until rice reached physiological maturity. The dates of several agronomic events are listed in Table 2. In general, rice management closely followed the University of Arkansas Cooperative Extension Service recommendations for stand establishment, pest management, irrigation management, and P and K application based on soil testing (Hardke, 2013).

Field Measurements

Plant samples of a 3-ft section were collected at 50% heading and used to determine N uptake in the plant (Guindo et al., 1994). Grain yield was determined at physiological maturity by harvesting 65-ft^2 from the middle 5 rows of each plot with a research grade plot combine. Grain weights and moisture contents were recorded and grain yields were adjusted to a uniform moisture content of 12% for statistical analysis.

Statistical Analysis

The experiment was a randomized complete block (RCB) with treatments defined by 2 N sources applied at 2 N rates with 3 N application times plus an unfertilized control (0 lb N/acre). Each treatment was replicated four times. Nitrogen uptake and rice grain yield data were analyzed using an analysis of variance (ANOVA). Nitrogen uptake and rice grain yield means were separated using Fisher's Protected Least Significant Difference test (LSD) at the $P < 0.05$ significance level where appropriate. All statistical analysis was conducted with the MIXED procedure in SAS v. 9.2 (SAS Institute Inc., Cary, N.C.).

RESULTS AND DISCUSSION

Rice Grain Yield

Daily maximum temperatures were in the 90-103 °F range which would presumably be conducive for NH_3 volatilization of urea (Table 3). The field in the study was flush irrigated prior to the 10 DPF N applications, and the field received a heavy rainfall of 3.5 inches 7 DPF. Muddy soil conditions can greatly exacerbate NH_3 volatilization of urea when fertilizers are surface applied. Thus, the environmental factors in the study were conducive for NH_3 volatilization loss of urea.

Rice grain yield was significantly affected by N rate × N timing ($P = 0.014$) and N source × N timing ($P = 0.0008$). Based on N rate × N timing, rice grain yield decreased as the time between N application and flooding increased at the 120 lb N/acre rate (Table 4). However when 60 lb N/acre was applied, the yield decreased as the time between N application and flooding increased from 1 DPF to 5 DPF and then remained the same between 5 and 10 DPF. The 5 and 10 DPF applications' yields were less than the 1 DPF application for both rates indicating that NH_3 volatilization occurred to a significant enough extent over the 5 to 10 days prior to flooding to decrease grain yield in this study.

Based on N source × N timing, untreated urea compared to urea + NBPT had greater yields when comparing the 5 and 10 DPF N application timings, indicating NBPT inhibited NH_3 volatilization in the trial (Table 5). The yield of 143 bu/acre when urea + NBPT was applied 5 DPF did not differ from the yield of urea + NBPT applied 10 DPF of 135 bu/acre. Yields were the greatest and similar to each other when applied 1 DPF indicating no significant NH_3 volatilization occurred over the 1 DPF.

Nitrogen Uptake Data

Nitrogen uptake data differed based on N rate × N timing ($P = 0.001$) and N source × N rate ($P = 0.01$). For N rate × N timing, when 60 lb N/acre was applied the N uptake of 63 lb N/acre for the 1 DPF application did not differ from the 10 DPF application N uptake of 54 lb N/acre (Table 6). The 1 DPF 60 lb N/acre N uptake was greater than the 5 DPF application N uptake of 48 lb N/acre, which did not differ from the 10 DPF application N uptake. The small sample size (i.e., 3-ft row section) used for determining N uptake lends the data to more variability than the yield data. Among the N application times at the 120 lb N/acre rate, the 10 DPF application had a lower N uptake at 66 lb N/acre than the 1 or 5 DPF N applications, which did not differ with N uptakes of 89 and 85 lb N/acre, respectively. Furthermore, the N uptake of 66 lb N/acre for the 10 DPF application at 120 lb N/acre did not differ from the N uptake of 63 lb N/acre for the 1 DPF application at 60 lb N/acre indicating that the 120 lb N/acre rate applied 10 DPF lost a substantial portion of the applied N during this study.

For the N source × N rate interaction, the N uptake was similar among the N sources at the 60 lb N/acre rate; however at the 120 lb N/acre rate, the urea + NBPT resulted in greater N uptake compared to untreated urea (Table 7). Urea + NBPT had the greatest N uptake in the study when 120 lb N/acre was applied with an N uptake of 86 lb N/acre.

SIGNIFICANCE OF FINDINGS

This study conducted during the 2013 growing season indicated that urea + NBPT was effective at decreasing NH_3 volatilization as compared to untreated urea. Grain yield was affected by N source and N application timing where urea + NBPT resulted in greater yields when applied 5 and 10 DPF as compared to untreated urea applied at these times. Also, N uptake was greater when urea + NBPT was the N source compared to untreated urea at the 120 lb N/acre rate. Thus, in accordance with prior studies, the use of the urease inhibitor NBPT was shown as an effective management strategy for decreasing N loss as NH_3 for preflood applications of urea in direct-seeded, delayed-flood rice production in Arkansas.

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Table 1. Selected soil chemical property means (n = 4) of research established at the Pine Tree Research Station in 2013.

	Mehlich-3 extractable nutrients							
pH	P	K	Ca	Mg	Na	S	Cu	Zn
7.3	39	142	1638	282	36	10	1.2	1.5

Table 2. Pertinent agronomic information for the research study at the Pine Tree Research Station during 2013.

Event		Dates
Planting date		20 May 2013
Emergence date		30 May 2013
Preflood N dates	10-day	14 June 2013
	5-day	19 June 2013
	1-day	23 June 2013
Flood date		24 June 2013
Harvest date		23 September 2013

Table 3. Air temperature and rainfall events during the 10 days of nitrogen (N) fertilization application prior to flood establishment at the Pine Tree Research Station during 2013.

		Air		
Date	DPF[a]	Max	Min	Rainfall
		---------- (ºF) ----------		(inches)
14 June 2013	10	102	65	0.00
15 June 2013	9	102	63	0.00
16 June 2013	8	99	69	0.00
17 June 2013	7	93	72	3.50
18 June 2013	6	95	67	0.00
19 June 2013	5	100	67	0.00
20 June 2013	4	99	69	0.00
21 June 2013	3	102	70	0.00
22 June 2013	2	103	72	0.00
23 June 2013	1	101	71	0.00

[a] DPF = days prior to flooding.

Table 4. Influence of nitrogen (N) fertilizer rate by N application time on rice grain yield during the 2013 season at the Pine Tree Research Station.

N fertilizer rate	N timing	Grain yield
(lb N/acre)	(DPF[a])	(bu/acre)
60	1	150
60	5	116
60	10	114
120	1	189
120	5	156
120	10	135
0	--	95
LSD (*P* < 0.05)		10

[a] DPF = days prior to flooding.

Table 5. Influence of nitrogen (N) source by N timing on rice grain yield during the 2013 season at the Pine Tree Research Station.

N source	N timing	Grain yield
	(DPF[a])	(bu/acre)
Urea	1	169
Urea	5	114
Urea	10	105
Urea + NBPT	1	169
Urea + NBPT	5	143
Urea + NBPT	10	135
LSD ($P < 0.05$)		13

[a] DPF = days prior to flooding.

Table 6. Influence of nitrogen (N) rate by N timing on 50% heading N uptake during the 2013 season at the Pine Tree Research Station.

N fertilizer rate	N timing	N uptake
(lb N/acre)	(DPF[a])	(lb/acre)
60	1	63
60	5	48
60	10	54
120	1	89
120	5	85
120	10	66
0	-	44
LSD ($P < 0.05$)		9

[a] DPF = days prior to flooding.

Table 7. Influence of nitrogen (N) source by N rate on 50% heading N uptake during the 2013 season at the Pine Tree Research Station.

N source	N rate	Uptake
	(DPF[a])	(lb/acre)
Untreated urea	60	51
Urea + NBPT	60	59
Untreated urea	120	64
Urea + NBPT	120	86
LSD ($P < 0.05$)		9

[a] DPF = days prior to flooding.

Validation of Soil-Test-Based Fertilizer Recommendations for Flood-Irrigated Rice

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ABSTRACT

Farmers depend on accurate interpretation of soil-test results for fertilizer recommendations. Our research objective was to develop an independent database of flood-irrigated rice (*Oryza sativa* L.) response to phosphorus (P) and potassium (K) fertilization to validate the accuracy of existing soil-test-based fertilization guidelines. Seven P and K fertilization trials were established in University of Arkansas System Division of Agriculture experiment station fields to validate soil-test-based fertilizer recommendations in 2013. Validation was based on three yield comparisons including P fertilizer alone compared to no fertilizer, K fertilizer alone compared to no fertilizer, and P and K fertilization compared to no fertilizer. Responses to soil-test-based crop response predictions to fertilization were designated as Correct, Type A Error, or Type B Error. The current soil-test-based recommendations for P and K fertilization of flood-irrigated rice were accurate at less than 50% of the seven sites that were established in 2013. Both soil-test P and K accurately predicted that rice grown on soils with Optimal or Above Optimal soil-test P and K levels would not respond to fertilization, but did poor jobs of predicting responses on soils that had ≤25 ppm P and ≤130 ppm K. First year validation trial results suggest soil-test P and K concentrations that define each soil-test level need to be redefined to improve their accuracy.

INTRODUCTION

Routine soil testing is used to determine how much phosphorus (P), potassium (K), and sometimes micronutrient fertilizers are needed to prevent nutrient availability from limiting crop yield. Since the early 1990s, grid soil sampling has become popular among many consultants and farmers and has replaced soil samples collected to determine the field-average nutrient availability and, along with variable rate fertilizer application, is part of precision agriculture. In Arkansas, since 2006, DeLong et al. (2013) reported that grid soil samples had increased by 18,424 samples per year and field-average soil samples had declined by 4,204 samples per year. Precision agriculture technologies are potentially valuable tools for crop and nutrient management, but the utility of variable rate fertilization is only as good as the accuracy of the soil-test-based nutrient management recommendations. Other than the statistics routinely reported with soil-test correlation-calibration research (Slaton et al., 2006; 2010), we could find no published information describing the accuracy of soil-test-based fertilizer recommendations. Our research objective was to develop an independent database of flood-irrigated rice response to P and K fertilization to validate the accuracy of existing soil-test-based fertilization guidelines. The overall research goal is to define the accuracy of soil-test-based recommendations for identifying whether the actual rice grain yield response would agree with the interpretation of the soil-test level definition. A secondary goal was to evaluate the accuracy of the recommended K fertilizer rate on responsive soils.

PROCEDURES

Seven P and K fertilization trials were established in University of Arkansas System Division of Agriculture experiment station fields across eastern Arkansas in 2013. Specific soil and agronomic information for each site is presented in Table 1. Each location will be referred to by the name listed in Table 1. Crop management practices including seeding rate, irrigation, N management, and pest control at all sites closely followed recommendations from the University of Arkansas Cooperative Extension Service. Rice was flood irrigated at the 5-lf stage following the application of preflood N. The preflood N rates at each site were 110 lb urea-N/acre at the Rice Research and Extension Center (RREC-E and -W), near Stuttgart, Ark., 130 lb urea-N/acre at the Pine Tree Research Station (PTRS-D12, -I8, and -MJC), near Colt, Ark., and 150 lb urea-N/acre at the Northeast Research and Extension Center (NEREC-E14 and -W6), near Keiser, Ark. A single application of 45 lb urea-N/acre was applied at midseason at PTRS-D12, -I8, and -MJC.

At each site, individual plots were 16- to 20-ft long and 9 rows wide with drill-row spacing of 7.0 or 7.5 inches. Preliminary soil samples or previous years' soil sample results from the field were obtained to estimate what the initial soil properties were before plots were established and used as a guide to determine the treatments that would be implemented at each site. Before fertilizer was applied to each site, a composite soil sample was collected from the 0- to 4-inch depth from each replicate (n = 6). Soil samples were oven-dried at 130 °F, crushed, and passed through a 2-mm sieve. More specific soil samples were eventually collected from each no fertilizer control plot. A second set of soil samples was also collected from the 0- to 12- or 0- to 18-inch soils depths and analyzed for N availability using N-ST*R. Soil water pH was determined in a 1:2 soil weight:water volume mixture, plant-available nutrients were extracted using the Mehlich-3 method, and elemental concentrations in the extracts were determined using inductively coupled plasma spectroscopy (ICPS). Selected soil chemical property means are listed in Table 2.

Each trial contained a total of six treatments that involved four K_2O rates and two P_2O_5 (0 and 60 lb P_2O_5/acre) rates including: 1) the recommended P rate plus 0 lb K_2O/acre, 2) the recommended P rate plus 60 lb K_2O/acre, 3) the recommended P rate plus 90 lb K_2O/acre, 4) the recommended P rate plus 120 lb K_2O/acre, 5) the recommended K rate plus the second or alternative P rate, and 6) no P and K fertilizer (control). Only two P rates were used because research in Arkansas has shown the relationship between crop yield and soil-test P is weak ($r^2 < 0.17$, Slaton et al., 2006). Triple superphosphate (46% P_2O_5) and muriate of potash (60% K_2O) were used as the nutrient sources. Zinc was also applied to the seed at all sites and applied to rice foliage after emergence at selected sites to ensure that Zn deficiency was not growth and yield limiting.

At the midtillering stage, a 3-ft section of row from three treatments including the no P and K control, and the two treatments that contained the two different P rates with the same K fertilizer rate was collected from the first interior row of every plot. Plant samples were also collected from treatments 1 to 4 at the late boot to early heading stage to evaluate rice tissue K concentration. The sample was oven dried to a constant weight, weighed, and a subsample was ground, digested, and analyzed for elemental concentrations by ICPS. A subsample of the harvested seed was also saved from each plot to examine the effect of fertilization on seed nutrient concentration. Leaf and seed nutrient composition will not be included in this report. Five to 8 of the 9 rows of each plot were harvested with a plot combine, grain moisture and weight was recorded, and rice grain moisture was adjusted to 12% for final yield calculations.

Each trial contained 6 treatments arranged as a randomized complete block design with 6 blocks. For each trial, analysis of variance (ANOVA) was conducted by site with the MIXED procedure in SAS v. 9.2 (SAS Institute, Inc., Cary, N.C.). Single-degree-of-freedom contrast statements were used to make specific comparisons among treatments. The three yield comparisons that will be reported include 1) P fertilizer alone compared to no fertilizer, 2) K fertilizer alone compared to no fertilizer, and 3) P and K fertilization compared to no fertilizer. For this report, significant yield differences were identified for comparisons at three levels of significance, 0.05, 0.10, and 0.25. Responses to fertilization were designated as Correct, Type A Error, or Type B Error. Our hypothesis for testing was that soils with Very Low or Low soil-test nutrient levels should respond positively to fertilization, and soils with Optimum or Above Optimum soil-test levels would not respond positively or negatively to fertilization. For soils having a Medium soil-test level, either no response or a small positive response would be expected and therefore either was considered as a correct outcome.

RESULTS AND DISCUSSION

Soil-test results indicated that rice yield increases from P and/or K fertilization were expected at five of the seven research sites. The seven sites represented all five soil-test P levels, but only three of the five soil-test K levels (no sites had Very Low or Optimum soil-test K). Rice yield responses to P fertilization, K fertilization, or the combination of P and K fertilization are summarized in Table 3. The seven sites included two clayey soils and five silt loams. Of the seven sites, no P or K fertilizer was recommended on the two clayey soils (NEREC), which had Optimum or Above Optimum soil-test P (≥36 ppm) and K (≥131 ppm) levels. The addition of P or K had no influence on rice yield for evaluations made at 0.05 or 0.25 indicating that recommendations accurately predicted no rice response to P and K fertilization.

The five silt loam soils had Very Low (1), Low (3), or Medium (1) soil-test P levels (plus soil pH >6.0) and would have received a recommendation for P fertilizer (Table 4). In our interpretation we considered the no response at the RREC-E site, which had a Medium soil-test P level to be correct because the Medium level is considered as the area of relative uncertainty and the prediction is considered correct if no yield increase occurs or a yield increase occurs. Phosphorus fertilization increased rice grain yield at none of the five sites, but decreased yield at two of the sites (mean loss 5.6%) when results were interpreted at $P = 0.25$. Therefore, the soil-test P interpretation correctly identified the response to P fertilization at only one of the four sites having suboptimal soil-test P. For all sites, soil-test P accurately predicted the need for P fertilization at 43% of the seven sites (Table 5).

Soil-test K was Medium at three sites (PTRS-D12, RREC-E, and RREC-W) and Low at two sites (PTRS-I8 and PTRS-JC), but rice yield at none of the five sites benefited from K fertilization (Table 3). Similar to P, K fertilization actually decreased yield at one (7% loss, $P = 0.05$) or two (average 4.5% loss, $P = 0.25$) of the five sites, depending on the significance level at which the results were interpreted. The current interpretation of soil-test K accurately predicted yield response to K at four ($P = 0.05$) or three ($P = 0.25$) of the seven sites (Tables 4 and 5). The most common error made by the existing soil-test K based recommendations was a Type B error in which the current interpretation recommended K fertilization, but rice yield was not affected (Table 5).

SIGNIFICANCE OF FINDINGS

The current soil-test-based recommendations for P and K fertilization of flood-irrigated rice were accurate at less than 50% of the seven sites that were established in 2013. Both soil-test P and K accurately predicted that rice grown on soils with Optimal or Above Optimal soil-test P and K levels would not respond to fertilization, but did poor jobs of predicting responses on soils that had ≤25 ppm P and ≤130 ppm K. Although soil-test-based predictions on the anticipated plant yield responses to fertilization need to be accurate, it must be remembered that fertilizer rates are often based on a philosophy to either fertilize the crop or the soil (build and maintain soil fertility approach) rather than strict fertilizer rate calibration curves. These first year validation trial results provide initial evidence suggesting that soil-test P and K concentrations that define each soil-test level need to be redefined to improve their accuracy. Additionally, this research project includes other aspects and objectives that were not summarized in this report and information from these other objectives may eventually explain why certain errors occurred. Factors such as temporal and spatial variability (horizontal and vertical variability) of soil-test parameters within the research area and the short-term history of cropping and fertilization likely play important roles on crop response to fertilization.

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Table 1. Selected soil and agronomic information for phosphorus (P) and potassium (K) fertilization trials conducted in 2013.

Site[a]	Soil series	Variety	Previous crop	Tillage[b]	Row width	Plant date
PTRS-D12	Loring	Roy J	Soybean	NT	7.5	17 April
PTRS-I8	Calloway	CL152	Soybean	CT	7.5	1 May
PTRS-MJC	Calhoun	CL152	Soybean	CT	7.5	17 April
RREC-E	Dewitt	CL152	Soybean	CT	7.0	15 May
RREC-W	Dewitt	CL151	Soybean	CT	7.0	17 April
NEREC-W6	Sharkey	CL152	Soybean	CT	7.0	28 May
NEREC-E14	Sharkey	CL152	Soybean	CT	7.0	30 May

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

[b] NT = no-tillage; CT = conventional tillage.

Table 2. Selected soil chemical property means (n = 5-6) from the unfertilized control in phosphorus (P) and potassium (K) fertilization trials conducted at multiple sites during 2013.

	4-inch Sample[b]							12- or 18-inch Sample[b]		
Site[a]	pH	P	K	Ca	Mg	S	Zn	pH	P	K
		------------------------------------(ppm)------------------------------------							------(ppm)----	
PTRS-D1218	7.0	23 (3)	108 (6)	1670	258	6	1.8	6.2	3 (<1)	60 (5)
PTRS-I818	6.9	16 (1)	70 (9)	1557	244	6	1.8	6.5	9 (4)	53 (9)
PTRS-JC18	7.1	16 (2)	70 (8)	1614	343	10	1.4	4.9	3 (<1)	50 (8)
RREC-E18	6.5	26 (3)	104 (10)	1398	129	9	2.1	6.1	7 (2)	88 (12)
RREC-W18	6.2	7 (2)	115 (50)	1085	182	8	0.9	5.7	1 (<1)	75 (15)
NEREC-W12	7.5	62 (3)	362 (16)	5115	931	8	3.8	7.4	42 (6)	321 (67)
NEREC-E12	6.7	43 (2)	279 (25)	3733	758	10	4.1	6.9	30 (3)	242 (53)

[a] Abbreviations include: PTRS, Pine Tree Research Station; RREC, Rice Research and Extension Center; and NEREC, Northeast Research and Extension Center. The letter or letters after the site abbreviation represent the field name and the superscripted value indicates the depth of the second set of soil samples presented in the three right-hand columns that were taken in addition to the 0- to 4-inch depth.

[b] The value in parentheses is the standard deviation of the mean soil-test P or K value.

Table 3. Expected rice yield response to phosphorus (P), potassium K, or P and K fertilization compared to a no P and K control at nine research sites established during 2013.

Site[a]	Expected response[b]		Check	Yield response to[d]					
	P	K	yield[c]	P Fert.	K Fert.	P & K Fert.	P Fert.	K Fert.	P & K Fert.
			(bu/acre)	------------------(*P*-value) ----------------			----- [Yield difference (bu/acre)]-------		
PTRS-D12	Yes	Maybe	251	0.1135	0.0392	0.2326	-14	-18	-8
PTRS-I8	Yes	Yes	236	0.0579	0.2952	0.0593	-10	-5	-8
PTRS-JC	Yes	Yes	210	0.9182	0.7612	0.9180	-1	+1	+1
RREC-E	Maybe	Maybe	206	0.3226	0.5712	0.3170	-6	-3	-5
RREC-W	Yes	Maybe	222	0.6452	0.2421	0.2008	-3	-4	-6
NEREC-E	No	No	178	0.9653	0.5535	--	0	-2	--
NEREC-W	No	No	161	0.8921	0.2518	--	0	-3	--

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

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

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

[d] Yield response: P Fert., single-degree-of-freedom contrast comparing the yield with no P or K to P fertilizer; K Fert., single-degree-of-freedom contrast comparing the yield with no P or K to K fertilizer; and P & K Fert., single-degree-of-freedom contrast comparing the yield with no P or K to that of soybean fertilized with both P & K fertilizer. Cells with '--' indicates that the treatment was not represented in the trial. The P & K comparison was used when the comparison involving only one nutrient was absent.

Table 4. Summary of rice yield responses to phosphorus (P) and potassium (K) fertilization at three levels of significance (*P* = 0.05, 0.10, and 0.25) as categorized by soil-test P and K level.

	Soil-test concentration		Phosphorus			Potassium		
Soil-test level	P	K	0.05	0.10	0.25	0.05	0.10	0.25
	-----(ppm)----		(Sites with yield differences/total number of sites[a])					
Very Low	≤15	≤60	0/1	0/1	0/1	0/0	0/0	0/0
Low	16-25	61-90	0/3	1(-1)/3	2(-2)/3	0/2	0/2	0/2
Medium	26-35	91-130	0/1	0/1	0/1	0(-1)/3	0(-1)/3	0(-2)/3
Optimum	36-50	131-175	0/1	0/1	0/1	0/0	0/0	0/0
Above Optimum	≥51	≥176	0/1	0/1	0/1	0/2	0/2	0/2

[a] Negative numerator value in parentheses indicates that the yield difference was significant but negative.

Table 5. The accuracy of soil-test prediction of rice yield response to fertilization at seven research sites in 2013 as defined by soil-test phosphorus (P) and potassium (K) level and the level of significance at which statistical comparisons were made.

			Interpreted at *P*-value ≤0.05[b]			Interpreted at *P*-value ≤0.25		
Nutrient	Soil-test range[a]	Total trials	Test success	Type A error	Type B error	Test success	Type A error	Type B error
			------------------------------- (% of sites) ------------------------------					
P	≤25	4	0	0	100	0	0	100[c]
P	26-35	1	100	0	0	100	0	0
P	≥36	2	100	0	0	100	0	0
P Summary	7	43	0	57	43	0	57	
K	≤90	2	0	0	100	0	0	100
K	91-130	3	67	0	33[d]	33	0	67[d]
K	≥131	2	100	0	0	100	0	0
K Summary	7	57	0	43	43	0	57	

[a] Ranges are grouped as Suboptimal (≤25 ppm and ≤90 ppm K, including the Very Low and Low levels in which a positive yield response is expected); Medium (26 to 35 ppm and 91 to 130 ppm K, response is unpredictable meaning no yield increase or a slight increase is expected); and Optimal (≥36 ppm and ≥131 ppm K including the Optimum and Above Optimum levels in which no yield increase or decrease expected).

[b] Type A Error occurs when the soil-test predicts that soil nutrient (P or K) availability is Optimal but subsequent yields are reduced by nutrient (P or K) deficiency (False Positive). Type B Error occurs when the soil-test predicts that soil nutrient (P or K) availability is suboptimal but subsequent yields do not respond to fertilization with that nutrient. (False Negative)

[c] Two of 4 sites actually responded negatively to P fertilization.

[d] One (0.05) or 2 (0.25) of the 3 sites actually responded negatively to K fertilization.

RICE CULTURE

Rice and Soybean Response to Short- and Long-Term Phosphorus and Potassium Fertilization Rate

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ABSTRACT

Knowledge of soil and crop yield response to long-term fertilization practices is important for sustainable soil nutrient and crop management. Our research objectives were to evaluate long-term rice (*Oryza sativa* L.) and soybean [*Glycine max* (L.) Merr.] growth and yield and soil-test phosphorus (P) and potassium (K) responses across time to P- and K-fertilization rates on silt-loam soils. Long-term field trials that have been cropped to a rice-soybean rotation at the University of Arkansas System Division of Agriculture Pine Tree Research Station (PTRS, Calhoun silt loam) and Rice Research Extension Center (RREC, Dewitt silt loam) were established in 2002 and 2007, respectively, and were continued in 2013. The Dewitt silt loam required about 8 lb K_2O and 18 lb P_2O_5/acre to increase soil-test K or P values, respectively, by 1 ppm. The Calhoun silt loam requires 37 lb K_2O/acre to increase soil-test K by 1 ppm. Rice and soybean yields on the Calhoun soil during the last 4 years have been increased by 9% to 21% and 7% to 72%, respectively, compared to the no-K control yields. Although positive yield responses from P or K fertilization are sometimes measured on the Dewitt soil, the differences after 6 or 7 years are not yet consistent across time or crop, but results suggest that soil-P and -K availability is gradually being depleted and significant yield differences among annual fertilization treatments may be imminent.

INTRODUCTION

The process of developing soil-test-based fertilizer recommendations for crop production contains multiple steps including correlation of soil test, calibration of fertilizer rates or selecting a fertilization philosophy, and validating the accuracy of the recommendations. The correlation and calibration components require years of research across numerous sites that represent a range of soil nutrient availability index values, soils, variety, and environmental conditions. The use of long-term fertilizer rate plots is important to this process because over time, soils with a range of nutrient availability index values are created and allow researchers to document the rate at which soil nutrients are depleted or accumulated. Such knowledge is useful in selecting the proper time interval for building soil nutrient concentrations for the build and maintain (or build the soil) philosophy.

Arkansas soils used for rice and soybean production tend to have lower soil-test P and K values than soils used for the production of other crops, but the median value of these soils tends to be slightly above the critical concentration (DeLong et al., 2013). Among the greatest challenges for developing fertilizer recommendations is finding soils that respond positively to fertilization. Soils that produce nutrient deficiencies are sometimes difficult to find. In Arkansas, finding undisturbed soils in which rice and soybean respond positively to P fertilization has been especially difficult. The long-term plot approach should aid our understanding of soil-nutrient availability and eventually create nutrient-deficient soils that will facilitate research, development of more specific recommendations, and aid farmer and agent training. Our research goals are to evaluate: i) long-term rice and soybean growth and yield and ii) soil-test P and K responses across time to P- and K-fertilization rates on silt-loam soils. This report summarizes our objective of monitoring these responses in long-term fertilization trials during the 2013 growing season and provides the rice or soybean yield data from one to three previous years.

PROCEDURES

Long-term field trials at the University of Arkansas System Division of Agriculture Pine Tree Research Station (PTRS) and Rice Research Extension Center (RREC) were continued in 2012. The PTRS trial was established in 2002 on a Calhoun silt loam and the RREC trial was established in 2007 on a Dewitt silt loam. Both research areas have been cropped to a 1:1 rice-soybean rotation. The same (or similar) P or K fertilizer treatments have been applied to each plot since the trials were initiated. Composite soil samples (0- to 4-inch depth) were collected from each plot in mid to late winter of 2013. Soil samples were dried at 55 °C in a forced-draft oven, crushed, soil water pH was determined in a 1:2 soil weight-water volume mixture by electrode, and subsamples of soil were extracted using the Mehlich-3 method. Elemental concentrations of the Mehlich-3 extracts were determined by inductively coupled plasma emission spectroscopy (ICPS). Selected soil chemical properties for each experiment are listed in Table 1. Triple superphosphate was broadcast to K trials before planting to provide 50 to 60 lb P_2O_5/acre and 60 to 80 lb K_2O/acre was broadcast as muriate of potash to the P-rate trial at the RREC. Both sites have been cropped with no-tillage except in years when tillage was required to remove tire ruts. Soil-test and crop-yield results have been summarized and reported in previous years (Slaton et al., 2011a, b).

Potassium fertilizer rate trials are conducted at both sites with common rates of 0, 40, 80, 120, and 160 lb K_2O/acre/year applied as muriate of potash. The influence of P-fertilizer rate is evaluated only at the RREC and includes 0, 40, 80, 120, and 160 lb P_2O_5/acre/year applied as triple superphosphate. Fertilizer treatments were applied shortly before or after planting rice at each site. The rice cultivar CL152 (treated with 7 oz CruiserMaxx/cwt) was drill-seeded (90 lb/acre) into the previous year's soybean residue at the PTRS and the RREC on 17 April. Management of rice with respect to stand establishment, pest control, irrigation, and other practices closely followed University of Arkansas Cooperative Extension Service guidelines for direct-seeded, delayed-flood rice production. Each plot at the PTRS was 24 ft wide (36 rows of rice per plot) and 16 ft long with a 1 to 2.5-ft wide alley surrounding each plot. At the RREC, plots were 15 ft wide and 25 ft long and each plot contained 24 rows of rice.

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% moisture by weight for statistical analysis.

Each experiment was a randomized complete block (RCB) design. The PTRS K trial contained nine blocks and the RREC P and K trials each contained six blocks. Analysis of variance was performed with the MIXED procedure in SAS v. 9.2 (SAS Institute, Inc., Cary, N.C.) with significant differences interpreted when $P < 0.10$. Mean separations were performed by Fisher's Protected Least Significant Difference test.

RESULTS AND DISCUSSION

Soil-test P and K values have been significantly changed by long-term P and K fertilization. Although the soil K response to annual fertilization at the two sites was not statistically compared, the rate of soil-test K change was numerically different between the Calhoun and Dewitt silt loams (Tables 2 and 3). At the PTRS, the mean annual soil-test K within each K rate has fluctuated 9 to 19 ppm during the last 4 years. For samples collected in 2013, the mean soil-test K range among annual-K rates was 41 ppm with soil-test K increasing linearly as annual-K rate increased (Table 2). The inverse of the linear slope indicates that 37 lb K_2O/acre is needed to increase soil-test K by 1 ppm over the 10 years of cropping and fertilization. Numerically, the 2013 slope was intermediate among the four annual slope values, suggesting that the fluctuation of soil-test K among years (0.019 to 0.039 ppm K/lb K_2O) is large enough to justify averaging the annual slopes of this long-term trial to find the most appropriate mean coefficient for predicting the rate of soil-test K change (e.g., for building soil-test K).

At the RREC, the fluctuation in soil-test K within an annual-K rate during the last two years ranged from 5 to 26 ppm, which was comparable to that found over a four-year period in the PTRS trial (Table 3). However, despite the shorter duration of fertilization and cropping, the range of soil-test K values among annual-K rates during the last 2 years at the RREC was 80 to 113 ppm, which was much larger than the soil-test K range at the PTRS (Table 2). The inverse of the linear slope coefficient at the RREC indicates 6.5 to 7.9 lb K_2O are needed to increase soil-test K by 1 ppm (Table

3), values that are much lower than found for the Calhoun silt loam at the PTRS (Table 2). These results indicate that soil-K fixation is much greater in the Calhoun soil than in the Dewitt soil. Soil-test P on the Dewitt silt loam has increased as annual-P fertilizer rate has increased (Table 3) with the greatest numerical changes between years occurring for annual rates >40 lb P_2O_5/acre. The rate of soil-test P change for the last two years has been relatively consistent showing 17.8 to 18.5 lb P_2O_5/acre are required to increase soil-test P by 1 ppm.

Rice and soybean grain yields at the PTRS long-term K trial have responded positively to K fertilization during the last 4 years (Table 4). Compared to the no-K control yields, rice fertilized with 80 to 160 lb K_2O/acre has produced 9% to 21% greater yields. Application of 40 lb K_2O/acre has also produced greater yields than the no-K control, but yields have generally been lower than yields from the annual-K rates of ≥80 lb K_2O/acre. Maximum numerical rice yield has been produced by application of 160 lb K_2O/acre. Soybean yields have shown similar results with soybean fertilized with 80 to 160 lb K_2O/acre producing 7% to 72% greater yields than soybean receiving no K.

Rice and soybean yield responses to P and K fertilization have not been consistent across the duration of these trials (since 2007) or during the last 2 years (Table 5). Soybean responded to P fertilization in 2012, but the response was not consistent across P rates. Rice yields decreased numerically, but not significantly as annual-P rate increased. Results from 2013, represent the seventh year of cropping and fertilization in this trial and indicate that soil-test (Mehlich-3) P values considered Very Low (<16 ppm) are not accurate predictors of crop response to P fertilization. Yield results in the K trial show no strong and common trend in yield response to K fertilization for both rice and soybean. In 2012, soybean yields were not different among annual-K rates, but showed a nonsignificant trend for yields to be numerically greater when K was applied. For rice in 2013, application of 40 and 80 lb K_2O/acre/year increased yield compared to the no-K control, but rates >80 lb K_2O/acre/year produced similar yields as the no-K control. The results do hint that K availability is gradually declining and is nearing the point that consistent grain yield responses will be measured in both crops.

SIGNIFICANCE OF FINDINGS

Long-term P and K fertilization trials on two silt loam soils show that soil-test K responds differently to K fertilization. The Dewitt silt loam requires only about 8 lb K_2O/acre to increase soil-test K by 1 ppm whereas the Calhoun soil requires 37 lb K_2O/acre to increase soil-test K by 1 ppm. Although both are silt loams, their clay mineralogy is different and is one, and perhaps the major, reason for the observed differences. Soil-test P on the Dewitt silt loam increases by 1 ppm for every 18 lb P_2O_5/acre applied. These results indicate that attempting to build soil-test P and K can be an expensive and long-term process. After 6 and 7 years of cropping and fertilization, rice and soybean yields on the Dewitt silt loam have not yet shown consistent positive benefits from annual fertilization. In contrast, both rice and soybean yields show consistent yield benefits from K fertilization on the Calhoun soil which had lower initial and current K availability indices than the Dewitt soil.

The crop yield results are invaluable for helping to develop soil-test-based fertilization guidelines and assess the accuracy of soil-test recommendations. Perhaps the most valuable asset of the long-term trials is that at some point the research plots will contain a range of soil P and K availabilities that will be most helpful in evaluating different or developing new soil-test methods.

ACKNOWLEDGMENTS

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Table 1. Selected soil chemical property means (0-to 4-inch depth, n = 6-9) of long-term plots used to evaluate rice and soybean response to P and K fertilization rate at the Pine Tree Research Station (PTRS) and Rice Research Extension Center (RREC) from soil samples collected in February 2013.

	Soil	Mehlich-3 extractable soil nutrients					
Site	pH[a]	P	K	Ca	Mg	S	Zn
		(ppm)					
PTRS-LT	8.0	28	NA[b]	2605	413	13	8.5
RREC-K	5.5	34	NA[c]	978	135	9	5.5
RREC-P	5.8	NA[c]	109	1076	144	9	5.9

[a] Soil pH measured in a 1:2 soil:water mixture.

[b] Mean soil-test K values for each annual K rate in the long-term trial are listed in Table 2.

[c] Mean soil-test K values for each annual K rate in the long-term trial are listed in Table 3

Table 2. Soil-test K of a Calhoun silt loam cropped to rice and soybean (Soy) as affected by annual-K rate for the last 4 years in the long-term trial at the Pine Tree Research Station (PTRS-LT) established in 2003.

Annual K rate	2010-Soy[a]	2011-Rice	2012-Soy	2013-Rice
(lb K_2O/acre/yr)	(ppm)			
0	60	49	64	60
40	64	57	73	64
80	69	66	78	69
120	73	78	82	79
160	82	94	91	101
$LSD_{0.10}$	6	6	6	12
P-value	<0.0001	<0.0001	<0.0001	<0.0002
C.V., %	11.0	9.9	9.7	20.0
Slope[b]	0.019[a]	0.039	0.017	0.027
R^2	0.52	0.83	0.52	0.53

[a] Plots were cropped to a 1:1 rice-soybean rotation. The year listed indicates the year that soil samples were collected. For example, results listed for 2010 represent soil samples collected in the later winter (e.g., February) of 2010 following the 2009 rice crop before soybean was planted in spring 2010. The crop listed by each year is the crop that was planted that year.

[b] Regression analysis was performed on soil-test values from four replicate plots that had received annual-K fertilization since 2003 (note the annual rates were changed to the listed values after 2006). Soil-test K values were regressed across the cumulative lb K_2O/acre applied.

Table 3. Soil-test P and K of a Dewitt silt loam as affected by annual P and K rates for the last 2 years in the long-term trial that was established in 2007 at the Rice Research Extension Center (RREC).

	Potassium (Trial ID 95)		Phosphorus (Trial ID 97)	
Annual rate	2012[a]	2013[b]	2012[a]	2013[b]
(lb P_2O_5 or K_2O/acre/yr)	(ppm)			
0	105	82	13	12
40	126	100	22	21
80	142	133	30	36
120	156	161	44	50
160	185	205	55	65
$LSD_{0.10}$	12	16	5	4
P-value	<0.0001	<0.0001	<0.0001	<0.0001
C.V., %	8.6	11.5	16.1	11.1
Slope	0.153[c]	0.127[d]	0.0054[c]	0.056[d]
R^2	0.87	0.87	0.90	0.95

[a] Soil samples collected in late winter/spring 2012 following the 2011 rice crop.

[b] Soil samples collected in late winter/spring 2013 following the 2012 soybean crop.

[c] Regression of soil-test P values from 2012 soil samples after 5 years of cropping and cumulative P and K fertilization.

[d] Regression of soil-test P values from 2013 soil samples after 6 years of cropping and cumulative P and K fertilization.

Table 4. Rice (2010 and 2013) and soybean (Soy, 2010 and 2012) grain yield as affected by annual-K rate for the last 4 years in the long-term trial at the Pine Tree Research Station (PTRS-LT).

Annual K rate	2010-Soy	2011-Rice	2012-Soy	2013-Rice
(lb K_2O/acre/yr)	-----------------------------	(bu/acre)	-----------------------------	
0	25	149	60	198
40	34	159	65	209
80	39	170	64	216
120	38	166	66	221
160	43	180	65	226
$LSD_{0.10}$	3	9	3	5
P-value	<0.0001	<0.0001	0.0317	<0.0001
C.V., %	10.7	8.3	8.0	2.7

Table 5. Rice and soybean grain yield as affected by annual-P and -K rate for the last 2 years in the long-term trial that was established on a Dewitt silt loam in 2007 at the Rice Research Extension Center (RREC).

	Phosphorus (Trial ID 97)		Potassium (Trial ID 95)	
Annual rate	Soybean 2012	Rice 2013	Soybean 2012	Rice 2013
(lb P_2O_5 or K_2O/acre/yr)	-----------------------------	(bu/acre)	-----------------------------	
0	76	165	58	166
40	80	164	62	174
80	86	161	63	173
120	78	157	61	167
160	82	157	62	165
$LSD_{0.10}$	6	NS[a]	NS	7
P-value	0.0225	0.3013	0.6679	0.0635
C.V., %	6.4	5.3	9.2	4.0

[a] NS = nonsignificant.

Summary of the Nitrogen Soil Test for Rice (N-ST*R) Nitrogen Recommendations in Arkansas During 2013

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ABSTRACT

Traditionally nitrogen (N) recommendations for rice in Arkansas were based on soil texture, cultivar, and previous crop, often resulting in over-fertilization, thus decreasing possible economic returns and increasing environmental N loss. In 2011, Roberts et al., correlated several years of direct steam distillation results obtained from 45-cm soil samples to plot-scale N response trials across the state and developed a site-specific soil based N test for Arkansas rice. After extensive field testing, the Nitrogen Soil Test for Rice (N-ST*R), became available to the public in 2012. In an effort to summarize the effect of the N-ST*R program in Arkansas, samples submitted to the University of Arkansas N-ST*R Soil Testing Lab during 2013 were categorized by county and soil texture. Samples were received from 27 Arkansas counties, with Arkansas County and Mississippi County submitting the largest number of fields, with 57 and 51 fields respectively. The samples received were from 171 silt loam fields and 137 clay fields. The N-ST*R N rate recommendations for these samples were then compared to the producer's estimated N rate or 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 recommendation, no change in recommended N rate, or an increase in the N rate recommendation. Soil texture was found to be a significant factor ($P < 0.0001$) in the fields with a decrease in recommendation, but was found to not be significant in the fields that had an increase in recommendation. County was found to be a significant factor in fields that showed an increase ($P < 0.05$) and a decrease ($P < 0.0001$) in the N rate recommendation.

INTRODUCTION

Traditionally nitrogen (N) recommendations for rice in Arkansas were based on soil texture, cultivar, and previous crop (Norman et al., 2013), often resulting in over-fertilization, thus decreasing possible economic returns and increasing environmental N loss. For years researchers have tried to develop an N soil test that would allow them to better predict the actual N needs for a particular field. After many years of research at the University of Arkansas System Division of Agriculture, the long quest for soil-based N recommendation for rice came to fruition in 2010 when investigators expanded on research at the University of Illinois which used organic-N content in the form of amino sugars to predict corn response to N fertilizer (Khan et al., 2001). University scientists correlated several years of direct steam distillation (DSD) results obtained from 18-inch soil samples (Roberts et al., 2009), which quantifies the amount of N that will be plant available to rice during the growing season, to plot-scale N response trials across the state and developed a site-specific soil based N test for Arkansas rice (Roberts et al., 2011).

Direct-seeded, delayed-flooded 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 and consistent 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-ST*R), became available to the public for silt loam soils in 2012 with the initiation of the University of Arkansas N-ST*R Soil Testing Lab in Fayetteville, Ark. Later, researchers correlated DSD results from 12-inch soil samples to N response trials on clay soils (Fulford et al., 2013), and N-ST*R rate recommendations became available to producers for clay soils in 2013.

PROCEDURES

In an effort to summarize the effect of the N-ST*R program in Arkansas, samples submitted to the University of Arkansas N-ST*R Soil Testing Lab during 2013 were categorized by county and soil texture. The N-ST*R N rate recommendations for these samples were then compared to the producer's estimated N rate if supplied on the N-ST*R Soil Test Laboratory Soil Sample Information Sheet 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 recommendation, no change in recommended N rate, or an increase in the N rate recommendation. The resulting data was analyzed using JMP v. 10 (SAS Institute, Inc., Cary, N.C.).

RESULTS AND DISCUSSION

Samples were received from 304 fields which represented 69 farmers across 26 Arkansas counties (Table 1). Arkansas County and Mississippi County submitted the largest number of fields, with 57 and 51 fields, respectively. The samples received were from 171 silt loam fields and 133 clay fields (Table 2). There was a decrease in the N recommendation for 201 fields (~66% of fields submitted) with an average decrease of 33 lb N/acre. No net change in N recommendation was found for 16 fields, while 87 fields had an increase in N recommendation (~28%), with an average increase of 15 lb N/acre. Of the 201 fields where there was a decrease in the N rate recommendation, 105 of those were from silt loam fields and 96 came from fields labeled as clay, with an average decrease of 26 lb N/acre for silt loams and an average decrease of 42 lb N/acre for the clay soils. The fields where an increase in recommendation was found were from 57 silt loams and 31 clays with an average of 16 and 14 lb N/acre, respectively.

Soil texture was found to be a significant factor ($P < 0.05$) in the fields with an increase in recommendation, but was found to be slightly not significant in the fields that had a decrease in recommendation ($P < 0.0546$). The difference in significance may be due to soil texture variability, soil texture classification errors, the differences in sample depth and the N-ST*R calculations for the two textures. If soils could be better classified using soil chemical properties such as an estimated cation-exchange capacity or using Arkansas' soil association number, which is based on soil pH and Mehlich-3 extractable calcium, producers would have a better idea of the correct sample depth to use and provide a more reliable N rate recommendation.

County was found to be a significant factor in fields that showed both an increase and a decrease ($P < 0.0001$) in recommendation suggesting that while certain areas of the state do require more N to maintain yields, other areas may be prone to N savings potential due to cropping systems and soil series (Table 1). Arkansas County had both the highest number of fields submitted for evaluation, 57, and the highest number of fields with a decrease in N recommendation, 48 fields or 84% (Fig. 1 and Table 1), with an average decrease of 30 lb N/acre. Lonoke and Prairie counties exhibited the same general trend with 64% and 82% of the samples submitted resulting in a decrease in N-ST*R N recommendation with an average decrease of 23 and 20 lb N/acre, respectively. Craighead, Greene, Lawrence, and Cross counties also had similar trends; however the number of fields submitted was somewhat lower for these counties. Composed of predominantly silt loam soils well suited for rice production, it is no surprise that these counties are among the top ten 2012 Arkansas counties in harvested acres of rice.

It is important to note that some of Arkansas' top rice-producing counties did have a fairly low number of samples submitted during 2013 and more samples will need to be evaluated to determine the N-ST*R recommendation trends in the other parts of the state.

SIGNIFICANCE OF FINDINGS

These results show the importance of the N-ST*R program to Arkansas producers and can help target areas of the state that would most likely benefit from its implementation. The N-ST*R Soil Testing Lab is currently working to develop guidelines to more clearly identify when soils are clay versus silt loam and help producers choose the correct sampling depth for their field.

ACKNOWLEDGEMENTS

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Table 1. Distribution and change in N rate when the Nitrogen Soil Test for Rice (N-ST*R) was used in place of the standard N rate recommendation based on county.

		Decreased N-ST*R recommendation		Increased N-ST*R recommendation		
County	Number of fields submitted	Number of fields	Mean N decrease	Number of fields	Mean N increase	No change in recommendation
			(lb/acre)		(lb/acre)	
Arkansas	57	48	30.1	6	13.2	3
Chicot	14	8	50.0	6	24.2	-
Clark	1	1	5.0	-	10.3	-
Clay	15	6	17.1	8	-	1
Conway	1	1	20.0	-	-	-
Craighead	10	5	24.0	4	22.5	1
Crittenden	4	3	30.0	-	-	1
Cross	1	1	20.0	-	-	-
Desha	32	28	57.2	4	30.0	-
Drew	1	1	100.0	-	-	-
Greene	8	6	21.7	1	20.0	1
Independence	7	5	38.0	2	25.0	-
Jackson	29	13	47.7	15	11.7	1
Jefferson	1	1	35.0	-	-	-
Lawrence	2	2	59.0	-	-	-
Lee	1	-	-	1	5.0	-
Lincoln	2	2	39.5	-	-	-
Lonoke	25	16	22.5	8	12.5	1
Mississippi	51	27	23.9	19	11.6	5
Phillips	4	3	35.0	1	15.0	-
Poinsett	8	4	28.7	4	35.0	-
Prairie	22	18	20.3	2	12.5	2
Randolph	1	1	5.0	-	-	-
St. Francis	5	1	15.0	4	40.0	-
White	1	-	-	1	10.0	-
Yell	1	-	-	1	25.0	-

Table 2. Distribution and change in N rate when the Nitrogen Soil Test for Rice (N-ST*R) was used in place of the standard N rate recommendation based on soil texture.

		Decreased N-ST*R recommendation		Increased N-ST*R recommendation		
Soil texture	Number of fields submitted	Number of fields	Mean N decrease	Number of fields	Mean N increase	No change in recommendation
			(lb/acre)		(lb/acre)	
Clay	133	96	41.7	31	14.0	6
Silt loam	171	105	25.5	57	15.6	10
Total	304	201	33.3	87	15.1	16

Fig. 1. The number of fields sampled and submitted to the Nitrogen Soil Test for Rice (N-ST*R) lab during the 2013 growing season. Each county indicates the number of samples submitted and the percentage of those samples with either an increased or decreased N-ST*R N rate recommendation when compared to the traditional recommendation for a given soil texture.

Quantifying Chalkiness and Fissured Kernels in Thickness Fractions of Long-Grain Rice

B.C. Grigg and T.J. Siebenmorgen

ABSTRACT

Four lots of rough rice, comprising Wells and XL753 long-grain cultivars, having either superior or inferior milling qualities, were each thickness-graded into thin [< 2.00 mm (5/64ths inch)], medium [(2.00 mm (5/64ths inch) to 2.05 mm (5.125/64ths inch)], and thick [> 2.05 mm (5.125/64ths inch)] fractions. Milled rice yield (MRY), head rice yield (HRY), and chalkiness and fissured kernels of brown rice were determined for each fraction and lot. Milled rice yields of thick and medium kernels were greater than those of thin kernels. For superior lots, MRYs of thick fractions were equal to those of medium fractions; while for inferior lots, MRYs of thick kernels were greater than the medium kernels. For all lots, HRYs of medium fractions were greater than thin fractions. For superior lots, HRYs of thick kernels were statistically equal to those of medium kernels. However for inferior lots, HRYs of thick kernels were less than those of medium kernels. Chalkiness tended to be greatest in thin kernels for both cultivars studied, and fissuring tended to be most prevalent in thick kernels for Wells, but not for XL753. Both of the aforementioned defects apparently reduced HRYs. Thickness grading of long-grain rice could concentrate chalky and fissured kernels into alternative processing streams, thereby improving the milling and visual characteristics of the primary stream. However, economic and logistic impacts on commercial milling operations have yet to be considered.

INTRODUCTION

The economic value of rough rice (*Oryza sativa*) is largely determined by both milled rice yield (MRY) and head rice yield (HRY). Grigg and Siebenmorgen (2013) showed that removing thin kernels, with greater associated chalkiness, improved MRY and HRY of rice. Chalky kernels often break during milling, thus reducing HRY (Webb, 1985). Moreover, the domestic market downgrades chalky rice (USDA-FGIS, 2009), and chalkiness of head rice is an important factor for U.S. rice exports. Head rice yield is also reduced by kernel fissuring, the result of rapid moisture adsorption by kernels of low moisture content in the field, or of conditions occurring during the drying process (Schluterman and Siebenmorgen, 2007). Siebenmorgen et al. (1997) suggested that thicker, bolder kernels were more susceptible to fissuring than thinner kernels, a concept supported by Jindal and Siebenmorgen (1994). Thus, bulk lots were thickness graded to determine if the process could improve MRY and HRY through concentration and removal of both chalky and fissured kernels.

PROCEDURES

Four lots, comprising Wells and XL753 long-grain cultivars, having either superior (+) or inferior (-) bulk (unfractioned) milling qualities, were harvested in 2012 (Table 1). Lots were cleaned with a dockage tester (Model XT4, Carter-Day, Minneapolis, Minn.), and conditioned to 12.0% ± 0.5% moisture content (wet basis). Conditioning was carried out in a climate controlled chamber (79 °F and 56% relative humidity), regulated by a stand alone conditioner (Model 5580A, Parameter Generation & Control, Black Mountain, N.C.). Rough rice moisture contents were measured by drying duplicate samples at 265 °F for 24 h in a convection oven (Model 1370FM, Sheldon Mfg. Inc., Cornelius, Ore.). Lots were stored at 39 ± 2 °F, but were equilibrated to room temperature (72 ± 2 °F) for at least 24 h prior to thickness grading and sample preparation.

For each lot, approximately 50 lb of rough rice was thickness graded using a precision sizer (Model ABF2, Carter-Day, Minneapolis, Minn.). The sizer was equipped with rotary screens (12 inch diameter) 2.00 mm or 2.05 mm (5/64ths inch or 5.125/64ths inch, respectively) wide openings, resulting in three fractions: thin [< 2.00 mm (5/64ths inch)], medium [2.00 mm (5/64ths inch) to 2.05 mm (5.125/64ths inch)], and thick [> 2.05 mm (5.125/64ths inch)]. For determination of milling parameters, four replicate 150 g (5.3 oz) samples of rough rice from bulk (unfractioned) and thin, medium, and thick fractions of each lot were prepared. Corresponding 100 g (3.5 oz) samples were also prepared for measurement of brown rice properties. All samples were maintained in zippered, plastic bags at 72 ± 2 °F for up to one week prior to milling or quantification of brown rice properties.

Samples used for milling analysis were dehulled using a laboratory sheller (THU 35B, Satake Corporation, Hiroshima, Japan) with a roller clearance of 0.019 inch. The resultant brown rice samples were milled in a laboratory mill (McGill No. 2, RAPSCO, Brookshire, Texas) equipped with a 3.3 lb weight on the lever arm, situated 6 inches from the milling chamber centerline. Milled rice yield (the mass fraction of rough rice remaining after milling, including both head rice and broken kernels) and HRY (the mass fraction of rough rice that remains as head rice after milling) were determined. Head rice was separated from broken kernels using a sizing device (Model 61, Grain Machinery

Manuf. Corp., Miami, Fla.). Samples were milled to a target degree of milling (0.4 ± 0.05% surface lipid content, the mass percentage of extracted lipid relative to the head rice). A near-infrared-reflectance spectrometer (Model DA7200, Perten Instruments, Hägersten, Sweden) was used to determine surface lipid content of head rice.

For analysis of brown rice properties, 100 g (3.5 oz) samples of rough rice were dehulled using the previously described laboratory sheller; however, the roller clearance was increased to 0.021 inch to prevent any possible sheller induced fissuring. Remaining unhulled or broken kernels were then removed prior to analyses. Chalkiness and fissured kernel percentage were each quantified using 200 intact kernels of the brown rice, from all lots and thickness fractions. Chalkiness, as a percentage of measured brown rice kernel area, was determined using a scanning system (WinSeedle Pro 2005a™, Regent Instruments Inc., Sainte-Foy, Quebec, Canada). Fissured kernels, as the number percentage of brown rice kernels with at least one fissure, were determined using a grain scope (Model TX-200, Kett Electric Laboratory, Tokyo, Japan).

Statistical software (JMP v. 10.0, SAS Institute, Inc., Cary, N.C.) was used to analyze the data. Analysis of variance (ANOVA, $P = 0.05$) was conducted, and means separated, using the Tukey-Kramer Honestly Significant Difference procedure (HSD, $P = 0.05$).

RESULTS AND DISCUSSION

Bulk MRYs of superior and inferior lots of a cultivar were not different (Table 1). However, bulk HRYs differed, with HRY of Wells+ being 27 percentage points (pp) greater than Wells-, and HRY of XL753+ being 15 pp greater than that of XL753. Reduced HRYs for bulk lots appeared to be related to chalkiness and/or fissuring of brown rice.

Consistent with the report of Grigg and Siebenmorgen (2013), there was a general trend for increasing MRY with increasing kernel thickness (Fig. 1). For all lots, MRYs of the thin fraction were less than medium and thick fractions, and for inferior lots, MRYs of the thick fraction were greater than those of the medium fraction. However, the trends for HRY followed a different pattern. For all lots, HRYs of medium fractions were greater than those of thin fractions. The trend for reduced HRY of thin fractions was also shown by Grigg and Siebenmorgen (2013) and by Matthews and Spadaro (1976), and was likely the result of greater breakage of thin and immature kernels during milling operations. Head rice yields of thick fractions tended to decline from those of medium fractions. Sun and Siebenmorgen (1993) also reported a decline in HRY for kernels thicker than 2.05 mm (5.125/64ths inch).

Brown rice chalkiness decreased with increase in kernel thickness from the thin to the medium fraction. The only exception being the XL753+ lot, where chalkiness was unaffected by thickness grading (Fig. 2). Brown rice chalkiness was similar between the medium and thick fractions. The decrease in brown rice chalkiness with increase in kernel thickness has been reported by Grigg and Siebenmorgen (2013). Fissured kernels tended to be greater in low HRY lots of both cultivars when compared to superior lots

(Fig. 2); although, across thickness-fractions, trends in kernel fissuring varied by cultivar. The percentage of fissured kernels in brown rice increased with an increase in the thickness fraction for both Wells+ and Wells- lots. However, fissured kernels were not significantly different across thickness fractions of either the XL753+ or XL753- lots.

SIGNIFICANCE OF FINDINGS

Thickness grading of rough rice resulted in fractions with distinct properties. For all lots, there was a trend of increasing MRY with increasing kernel thickness. Head rice yields did not follow the same trend. For all lots, HRYs of the medium fraction were greater than those of the thin fraction. However, HRYs for the thick fraction tended to decline from that of the medium fraction, particularly for the inferior lots of both cultivars. Reduced HRYs were a result of greater brown-rice chalkiness and fissured kernels for the inferior HRY lots. Brown rice chalkiness tended to be greater for kernels of the thin fraction. Conversely, fissuring tended to increase as kernel thickness increased for Wells, but not for XL753. Thickness grading of long-grain rice could concentrate chalky and fissured kernels into alternative processing streams, thereby improving the milling and visual characteristics of the primary stream. However, economic and logistic impacts on commercial milling operations have yet to be considered.

ACKNOWLEDGMENTS

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Table 1. Description of bulk (unfractioned) properties of four lots, comprising two cultivars (Wells and XL753), each having superior (+) or inferior (-) bulk milling quality. All lots were harvested during the 2012 season from mid-South area production locations. Bulk milling properties include milled rice yield (MRY) and head rice yield (HRY) for rice milled to a target degree of milling (0.4 ± 0.05% surface lipid content). Bulk brown-rice properties include chalkiness (the percentage of measured area) and fissured kernels (the number percentage of kernels with at least one fissure).

Lot	Source	MRY	HRY	Chalkiness	Fissured kernels
		(%)			
Wells+	Strip trial, Bell City, Mo.	73	61	4	6
Wells-	Strip trial, Forest City, Ark.	72	34	5	14
XL753+	Research plots, RREC[a]	71	55	6	2
XL753-	Research plots, NEREC[b]	71	40	10	12

[a] Rice Research and Extension Center (RREC), University of Arkansas System Division of Agriculture, near Stuttgart, Ark.

[b] Northeast Research and Extension Center (NEREC), University of Arkansas System Division of Agriculture, near Keiser, Ark.

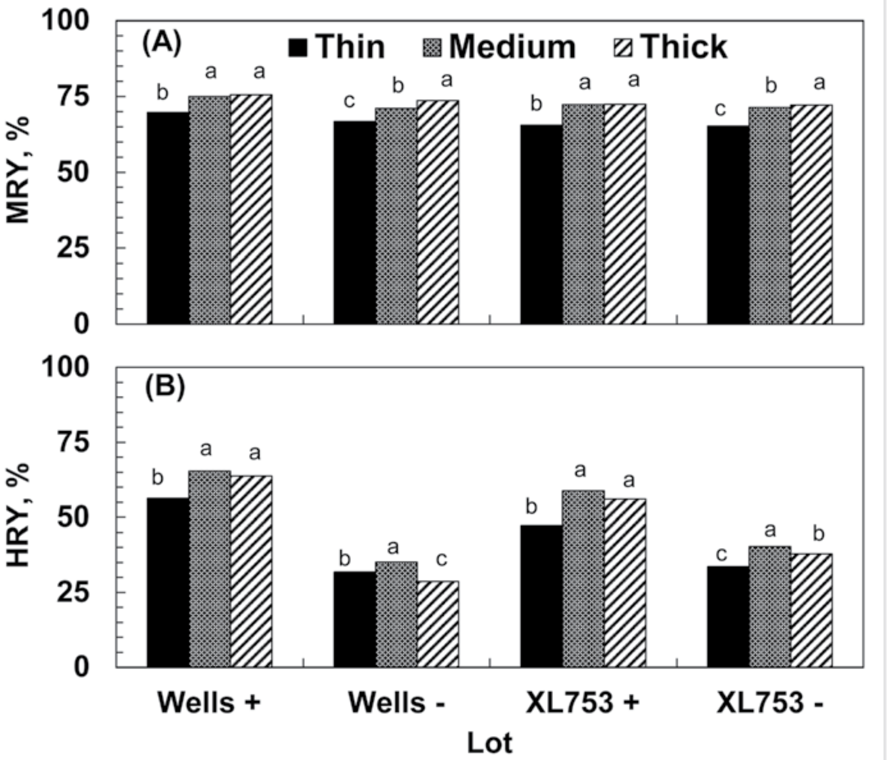

Fig. 1. Milled rice yield, MRY (A) and head rice yield, HRY (B) of rice for the indicated thickness fractions of four lots, comprising two cultivars (Wells and XL753), of both superior (+) or inferior (-) bulk milling qualities. All lots were harvested in 2012. Thickness grading of rough rice resulted in thin [< 2.00 mm (5/64ths inch)], medium [2.00 mm (5/64ths inch) to 2.05 mm (5.125/64ths inch)], and thick [> 2.05 mm (5.125/64ths inch)] fractions. All samples were milled to a target degree of milling (0.4 ± 0.05% surface lipid content). Within a lot, MRY or HRY values followed by the same letter are not significantly different (*P* > 0.05).

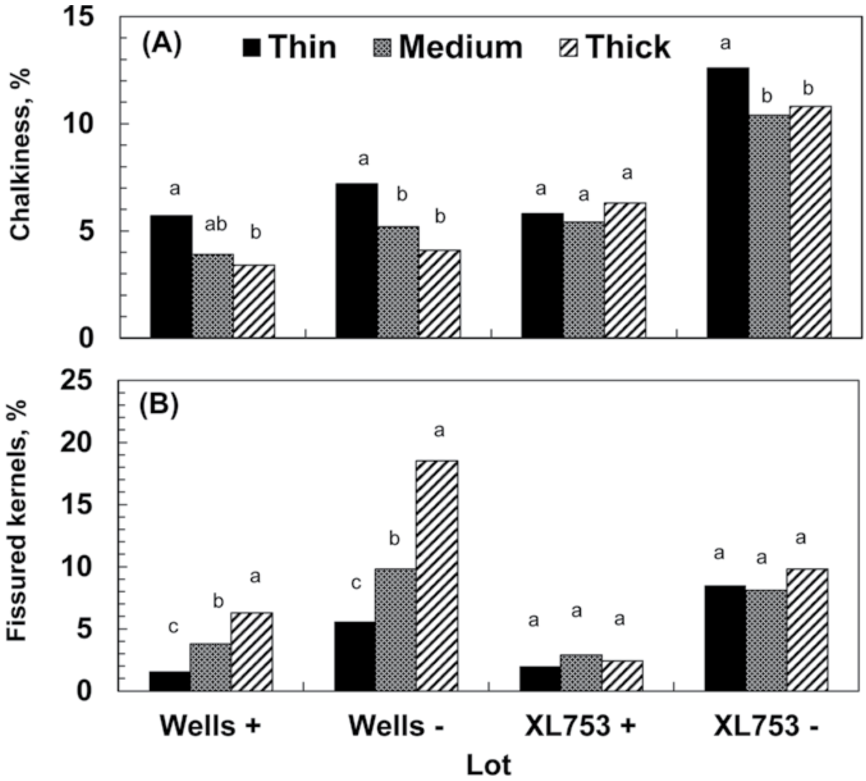

Fig. 2. Chalkiness, the percentage of measured kernel area (A) and fissured kernels, the number percentage of kernels with at least one fissure (B) of brown rice for the indicated thickness fractions of four lots, comprising two cultivars (Wells and XL753), of both superior (+) or inferior (-) bulk milling qualities. All lots were harvested in 2012. Thickness grading of rough rice resulted in thin [< 2.00 mm (5/64ths inch)], medium [2.00 mm (5/64ths inch) to 2.05 mm (5.125/64ths inch)], and thick [> 2.05 mm (5.125/64ths inch)] fractions. Within a lot, values of chalkiness or fissured kernels followed by the same letter are not significantly different (*P* > 0.05).

Gene Expression and Physiological Analyses to Study Grain Filling in *Oryza sativa* Japonica Varieties Cypress and LaGrue Subjected to High Nighttime Temperatures

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ABSTRACT

Starch composition and grain quality of rice is greatly influenced by genotype and environmental factors. The detrimental effects of high nighttime temperatures on rice yield and quality has recently become apparent, with some of the warmest average nighttime temperatures being recorded in the past few years. One of the highly noted effects of this stress, an increase in number of chalky grains, correlates with a decrease in quality. This effect varies greatly between cultivars as some show less temperature-sensitive quality reduction than others. The goal of this research is to elucidate fundamental changes that occur in developing plants and grains as they respond to high nighttime temperatures. For the purpose of this study, two cultivars were used: Cypress, considered to have greater tolerance to high temperatures; and LaGrue, considered to be more susceptible. To assess physiological differences between cultivars, gas exchange measurements were collected from field-grown plants to determine photosynthetic rates. Gene expression analysis was carried out using DNA gene strip arrays with tissue isolated from plants grown in temperature-controlled conditions, and it was instrumental in identifying genes that are differentially expressed in these cultivars.

Rice plants exposed to high nighttime temperatures have a significant reduction in yield and grain quality. Daily minimum (nighttime) temperatures are projected to increase faster than daily maximum (daytime) temperatures almost everywhere across the globe, leading to a decrease in the diurnal temperature range (Solomon, 2007). Reduced milling quality and overall yield is correlated with the increased amount of chalky endosperm that is the effect of exposure to high nighttime temperatures (HNT) during crucial times in grain filling. The opaque chalky appearance in the middle or the side of the endosperm is the direct result of an imperfect starch granule structure that leads to loose packing of the starch and amyloplasts (Lisle et al., 2000). Growth ring structures are observed in rice starch granules when plants are placed under a 12-h light/12-h dark regime, growth rings are absent under constant light (Yu et al., 2012). These observations indicate a diurnal fluctuation in starch biosynthesis. Further analysis of protein activities revealed that the enzyme involved in the first key regulatory step in starch biosynthesis showed increases at night, providing further indication that nighttime is mainly when carbon flows into the starch synthesis process (Jeon et al., 2010; Yu et al., 2012). An important study by Cooper et al. (2008) reported that U.S. rice cultivars varied in their production of chalky grains, indicating a genetic basis for chalk formation in response to environmental changes. Studies in the past have failed to find a correlation between increased photosynthetic rate and increased yield with the exception of soybean canopy photosynthesis and yield. Several studies revealed good correlations of either leaf or canopy photosynthesis and seed yield in soybean (Wells et al., 1986; Thompson et al., 1995; Jin et al., 2010). Moreover, heritabilities were shown to be greater for canopy photosynthesis than for seed yield (Harrison et al., 1981). A recent study by Long et al. (2006) revealed parallel increases in photosynthesis and yield in soybean grown under free-air carbon dioxide enrichment. This led to the exploration of photosynthetic differences between cultivars, with the idea that different amounts of sucrose from source to sink could influence varietal differences in chalk formation. To further investigate varietal traits that might confer tolerance to HNT, whole transcriptome analysis along with gas exchange measurements of photosynthetic rates were carried out on two long-grain cultivars one showing tolerance (Cypress) and another showing susceptibility to HNT (LaGrue).

PROCEDURES

Plant Growth and Tissue Collection

Plants used for gas exchange measurements to estimate photosynthetic rate were grown in flooded field plots in Stuttgart, Ark., two plots per cultivar. Readings were collected at three intervals at growth stages R2, R6, and R8.

For microarray and quantitative real-time reverse-transcription polymerase chain reaction (qPCR), analysis of gene expression cultivars Cypress and LaGrue were maintained in flooded pots, five sibling plants per pot, in the greenhouse until growth stage R4. At R4, one-half of the pots for each cultivar were transferred to each of two identical growth chambers. Daytime temperatures were identical in each chamber, 0600 to 1200 h at 25 °C; 1200 to 1600 h at 27 °C; and 1600 to 2100 h at 25 °C. Nighttime (dark) temperatures were set at either 18 °C or 30 °C from 2100 to 0600 h. When plants had reached growth stage R8, individual grains that were still in R7 to R8 (soft to hard dough stages) were collected at 1000 h and endosperm fractions were frozen in liquid nitrogen. For quantitative reverse-transcription (qRT) PCR validation of microarray results, plants were grown and maintained as before, but the dark period began at 2300 and ended at 0800. Panicles were collected at 0800 as soon as the daytime (light) period had begun and endosperm fractions were isolated from grains in the R7 to R8 stages.

Microarray and qRT-PCR Analyses

Total RNA was isolated from endosperm material using Masterpure Plant RNA purification kit (Epicentre Inc., Madison, Wis.). Total RNA from three independent samples from each treatment (Cypress 18 °C, Cypress 30 °C, LaGrue 18 °C, and LaGrue 30 °C) was analyzed via Affymetrix® U.S. Rice Gene 1.1 ST Array Strips at the University of Michigan. Expression values were analyzed for each gene using robust multi-array average (Irizarry et al., 2003). The expression values were $\log_2$ transformed data, fit to linear models designed for microarray analysis, and contrasted (Table 1). All analysis was done using Affymetrix and Limma packages of Bioconductor™ implemented in the R statistical environment.

For qRT-PCR, cDNA was generated with iScript cDNA synthesis kits (Bio-Rad, Hercules, Calif.). Gene-specific primers (Table 2) were used in standard qPCR reactions with a 1:5 dilution of each cDNA as template (1 µl/reaction) for each reaction. Reactions for qPCR were performed using Power SYBR® Green PCR master mix (Applied Biosystems) with 20-µL reaction volumes. An Applied Biosystems StepOnePlus™ real time PCR system was utilized to run the reactions with the following protocol: 1 cycle of 95 °C for 10 min and 40 cycles of 95 °C for 15 s and 62 °C for 1 min. Three technical reps were run for each biological rep. Relative gene expression ratios for each gene were calculated using the $2^{-\Delta\Delta Ct}$ method (Schmittgen and Livak, 2008) where $\Delta\Delta C_t$ is calculated as:

$$\Delta\Delta C_t = \Delta C_{t\,(\text{Cypress18 °C})} - \Delta C_{t\,(\text{LaGrue18 °C})} \qquad \text{Eq. 1}$$

$$\Delta C_t = C_{t\,(\text{Target})} - C_{t\,(\text{Reference})} \qquad \text{Eq. 2}$$

The mean C_t was calculated for each biological rep. For LaGrue samples only, the mean of the mean was calculated and this value was used in Eq. 2 which resulted in one ΔC_t value for each Cypress temperature treatment. For Cypress samples (e.g., nighttime temperatures 18 °C and 30 °C), the mean C_t was used in Eq. 2 which resulted in three ΔC_t values for each treatment. The $2^{-\Delta\Delta Ct}$ was then calculated. The mean $2^{-\Delta\Delta Ct}$ was calculated for Cypress samples and compared to the LaGrue used as control. Statistical analysis was performed using a one-sample t test ($P = 0.05$) with GraphPad Prism version 5.04 for Windows (GraphPad Software, San Diego, Calif., www.graphpad.com).

Photosynthesis Measurements

Gas exchange measurements were performed using the Li-Cor 6400XT Portable Photosynthesis System (Li-Cor, Lincoln, Neb., U.S.A.) in order to determine photosynthetic rate (µmol CO_2 m^{-2} s^{-1}). Using the 6400-02B LED light source, light intensity was set to 1300 µmol m^{-2} s^{-1}, air flow was adjusted to keep relative humidity above 50%, reservoir CO_2 was set at 375 ppm, and chamber block temperature was set to 24 °C. Temperature and CO_2 were approximately the same as ambient. For the R6 and R8 readings, the 6400-40 leaf chamber fluorometer was used to provide light. Using this light source, light intensity was set at 1200 µmol m^{-2} s^{-1}, relative humidity was held above 50%, reference CO_2 level was 375 ppm, and chamber block temperature was set to 25 °C to match ambient temperature and CO_2 levels. Statistical analysis was performed using an unpaired t test, two-tailed ($P = 0.05$) with GraphPad Prism version 5.04 for Windows (GraphPad Software, San Diego, Calif., www.graphpad.com).

RESULTS AND DISCUSSION

Photosynthetic rates measured in flag leaves were not significantly different between the cultivars in the early reproductive growth stage R2 (Cypress: 11.61 ± 0.4320; LaGrue: 10.53 ± 0.3872) (Fig. 1). Plants are classified growth stage R2 when the collar has formed on the flag leaf, just before panicle exertion from boot. Measurements were collected again once the plants had reached growth stage R6. During this stage a large proportion of grains are considered to be in the filling stage and the photosynthetic rates were significantly higher in LaGrue (Cypress: 15.22 ± 04034; LaGrue 17.98 ± 0.3562). The photosynthetic rates remained significantly higher in measurements collected during growth stage R8 (Cypress: 8.455 ± 0.4277; LaGrue: 11.74 ± 0.2960). The results in Fig. 2 show that rates were higher in both cultivars during growth stage R6 compared to rates during stages R2 and R8.

For a glimpse into gene expression of a high number of genes that are active at a certain time in developing endosperm, DNA gene chip technology was utilized. This provided a tool to compare gene expression activity in different tissues or cultivars. Replicated Affymetrix® array strip analyses revealed a list of candidate genes that are differentially expressed in endosperm of the two cultivars tested. A greater number of differentially expressed genes were observed when comparing cultivar samples at either temperature treatment, compared to temperature treatments within a cultivar. For example, a gene encoding a rice protein of unknown function and another encoding the storage protein glutelin showed a higher level of expression in Cypress compared with LaGrue (Table 1). In contrast, a gene encoding prolamin, also a putative storage protein, exhibited higher level of expression in LaGrue when compared with Cypress. Genes that displayed a large difference of expression between cultivars in the microarray analysis were selected as candidates for follow-up qPCR analysis. Expression of these genes as indicated by transcriptome analysis varied slightly from qPCR analysis (Fig. 1). Ubiquitin 5 was found to have the most stable expression across tissue and treatments by Jain et al. (2006) therefore it was chosen as the endogenous control for normalization of gene amplification signals.

SIGNIFICANCE OF FINDINGS

Experiments conducted in climate-controlled growth chambers were carried out with identical daytime temperatures and with nighttime temperatures of either 18 °C or 30 °C during reproductive stages. Although the tissue was collected in the morning rather than during the nighttime, the expression data still showed varietal differences. Candidate genes quantified by qPCR showed much higher expression in Cypress compared with LaGrue even when grown under a low nighttime temperature. Expression levels for putative protein prolamin have very low relative expression in Cypress relative to LaGrue at an 18 °C night temperature. Converse to this result, expression levels were the same between cultivars relative to one another under the high nighttime temperature treatment. Before the initiation of grain filling, photosynthetic rates were low in both cultivars and there was no significant difference between the rates as seen in Fig. 2. Both cultivars displayed an increase in photosynthetic rate during the R6 stage. When plants have reached the R6 stage, most if not all grains on the panicle have started the filling process. The cultivar LaGrue has more grains per panicle, higher yield, and more variable head rice yield than Cypress. Part of the increased head rice yield is likely related to a shortened duration for R8 (P.A. Counce, unpublished data). Growth stage R8 is when high night temperature effects on head rice yield are the greatest (Cooper et al., 2006; Lanning et al., 2011). There is considerable coordination of source and sink activity in plants. The greater number of grains per panicle and greater R8 duration for LaGrue compared to Cypress entails a longer duration for photosynthate demand by LaGrue sinks—the filling grains. Positive photosynthetic responses to sink demand have been determined with objective data in some cases (Gifford and Evans, 1981; Lauer and Shibles, 1987; Diethelm and Shibles, 1989; Wardlaw, 1990; Paul and Foyer, 2001; Smith and Stitt, 2007). The effect of sink stimulation on photosynthesis is the result of a complex set of feedback signals between the source and the sink. Source-sink coordination is both logical and verifiable but verifying the relationship requires extensive experimentation at both the whole plant level and at the gene expression level for individual source and sink tissue. Southern U.S. long-grain rice, for instance, differs greatly from high yielding Chinese *indica* rice such as Guichao2 for photosynthesis in the late reproductive growth stages such as R6, R7, and R8 (Black et al., 1995). Without further investigation, the relationship of photosynthesis and sink demand in LaGrue and Cypress is far from clear but the higher photosynthetic rate of LaGrue compared to Cypress is matched to the greater sink demand by filling grains for LaGrue at R8. Future experiments will include verification of the genetic identity of seed and leaf material used in this study.

ACKNOWLEDGMENTS

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Table 1. Differentially expressed gene in rice cultivars Cypress and LaGrue, as determined by analysis of Affymetrix® U.S. Rice Gene 1.1 ST Array Strips.

Cultivar showing higher expression	Gene description	LaGrue - Cypress 18 °C logFC[a]	Adj. *P*-value	LaGrue - Cypress 30 °C logFC[a]	Adj. *P*-value
Cypress	Plant protein domain of unknown function	-4.673	0.000	-4.883	0.000
Cypress	Glutelin, putative, expressed	-4.134	0.000	-2.458	0.002
Cypress	omega-3 fatty acid desaturase	-3.405	0.001	-3.369	0.001
Cypress	hAT dimerisation domain-containing protein	-2.769	0.001	-2.824	0.001
LaGrue	Similar to solute carrier family 35, member F1	1.866	0.027	2.815	0.003
LaGrue	PROLM27 - Prolamin precursor, expressed	2.071	0.021	2.300	0.014
LaGrue	No apical meristem putative protein	4.331	0.001	2.673	0.021

[a] logFC is the log value of signal fold-change comparing expression in LaGrue with Cypress at the same nighttime temperature treatment.

Table 2. Gene-specific primers for rice endosperm qPCR.

Gene description	Direction	Sequence	Predicated Length	product size
Plant Protein domain of unknown function	F	5’-CGAGCCCAAACACAACTACC-3’	20	
	R	5’-GCAGTGTCACGCAGTTCCTA-3’	20	101
Glutelin, putative, expressed	F	5’-GAGAACGAGGCCTCAGAGTG-3’	20	
	R	5’-GAACAGAACCGCCACAAAGT-3’	20	100
ω-3 fatty acid desaturase	F	5’-ACTTCACCTGTTTGGCGTTC-3’	20	
	R	5’-AGTCAGTGCCGTTCAAGCTG-3’	20	110
hAT dimerisation domain-containing protein	F	‘5-CTCGTAAATGGCAAGGTGGT-3’	20	
	R	‘5-TTCCCGGTTCAAAGAAAATG-3’	20	132
Similar to solute carrier family 35, member F1	F	‘5-GGGACTTGCATGACTGGACT-3’	20	
	R	‘5-CCACAATGATAAGGGCATCC-3’	20	109
PROLM27 - Prolamin precursor, expressed	F	5’-ACGGTCGGTGGTATCTGGTA-3’	20	
	R	5’-TGTATCGCCTCGATGTTTCA-3’	20	107
No apical meristem putative protein	F	5’-CAGCATCGACCTCGACATAA-3’	20	
	R	5’-GCCCAAAGAAGTACCACTCG-3’	20	110
Ubiquitin 5[a]	F	5’-ACCACTTCGACCGCCACTACT-3’	21	
	R	5’-ACGCCTAAGCCTGCTGGTT-3’	19	69

[a] Primers came from Jain et al., 2006.

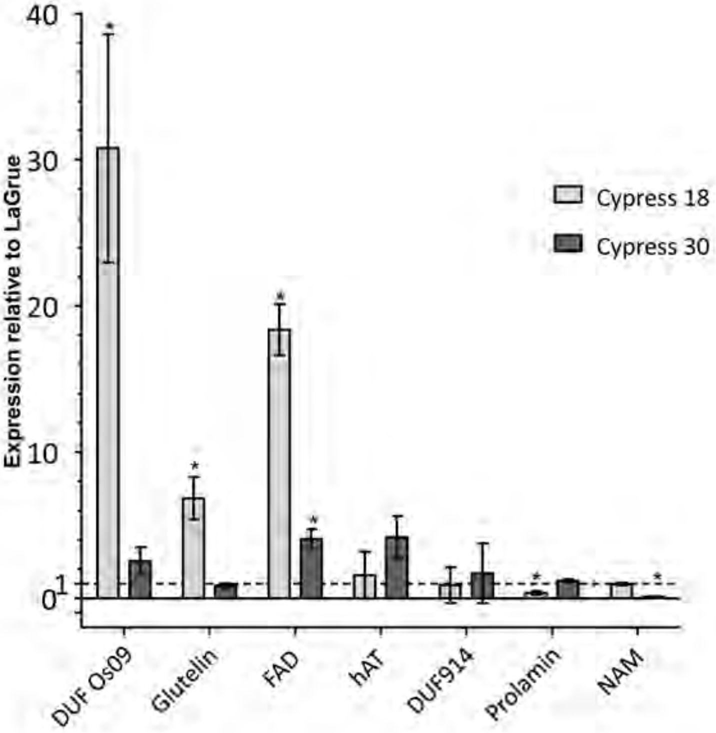

Fig. 1. Relative gene expression of Cypress exposed to 18 °C (light gray) and 30 °C (dark gray) nighttime temperatures when compared to LaGrue exposed to the same nighttime temperatures. Asterisk above the column indicates *P* value ≤0.05 (n = 3). Error bars indicate SD. Abbreviations: DUF Os09: Plant protein domain of unknown function; Glutelin: Glutelin putative, expressed; FAD: ω-3 fatty acid desaturase; hAT; hAT dimerization domain-containing protein; NAM: no apical meristem protein, putative, expressed; DUF914: eukaryotic protein of unknown function DUF914 domain containing protein; Prolamin: PROLM27 - Prolamin precursor, expressed.

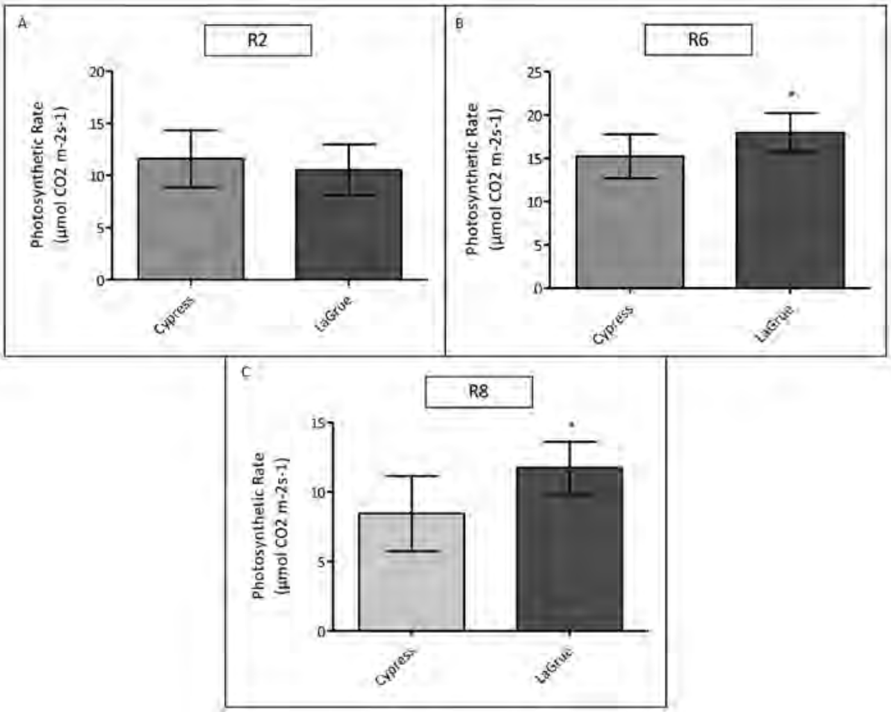

Fig. 2. Graphs indicate mean photosynthetic rates with standard deviation for cultivars Cypress and LaGrue located in field plots in Stuttgart, Ark. Asterisk above the column indicates a *P*-value of <0.01 (n = 80).

Effect of Degree of Milling and Kernel Thickness on Milled Rice Fissuring Rates

S. Mukhopadhyay, T.J. Siebenmorgen and A. Mauromoustakos

ABSTRACT

Fissuring induced by rapid moisture adsorption or desorption in milled rice reduces performance in end-use processing operations, thus causing substantial financial losses. This study investigated the effects of degree of milling and kernel thickness of milled rice kernels on fissuring rates in the long-grain, pure-line cultivar CL151 and long-grain, hybrid cultivar CLXL745. Samples from both cultivar lots were milled to four surface lipid content (SLC) levels (0.2%, 0.4%, 0.6%, and 0.8%). Non-fissured, non-chalky, head rice kernels were exposed to air conditions of 30 °C (86 °F) and relative humidities (RHs) of 20% and 80% for 4, 8, 16, 32, 60 and 120 min. Significant differences in fissuring rates were seen among various SLC levels; the fissured kernel percentage (FKP) increased with decreasing SLCs, and this effect was more pronounced at 80% RH. Additionally, samples of both cultivar lots were milled to 0.4% SLC and the head rice was divided into thin, medium, and thick kernel fractions. These were then exposed to the same temperature/RH/exposure duration combinations as above. Both the cultivar lots had greater fissuring rates for all three thickness fractions when exposed to the 20% RH environment as compared to the 80% RH condition. There were no significant differences among FKPs with varying kernel thicknesses for kernels exposed to the 20% RH setting for both cultivars, and also for CLXL745 kernels exposed to 80% RH air, for the entire exposure duration range. For the limited case in which kernel thickness was statistically significant for CL151 kernels exposed to 80% RH air for 16, 32, and 60 min, FKPs were not practically significant. This research showed that in general, rice milled to greater degrees of milling had greater fissuring rates and that kernel thickness did not practically impact milled rice fissure kinetics in environments similar to those used in this study.

INTRODUCTION

Fissuring in milled rice kernels causes substantial financial losses to post-milling processors in terms of product waste and throughput limitations (Siebenmorgen et al., 2009). Milled rice fissuring occurs when intra-kernel stresses exceed the tensile strength of the kernel; such stresses are primarily caused by rapid moisture transfer, in either direction, between a kernel and its surrounding environment. Siebenmorgen et al. (2009) showed that fissuring occurred particularly at very high (90%) and very low (10%) air relative humidities (RHs) for milled rice at moisture contents (MCs) of ~11% to 14%[1]; such air/rice conditions promote rapid moisture adsorption and desorption, respectively. Temperature played a much lesser, though significant, role in that the rate of fissuring was directly related to temperature increase. Lloyd and Siebenmorgen (1999) demonstrated that high MC rice was more susceptible to fissuring when exposed to low RHs, and vice-versa; both trends being explained by considerably greater rates of moisture transfer and resultant intra-kernel stress differentials.

In the rice-processing industry, rice lots are routinely milled to different degrees of milling [DOM, which is often measured by the surface lipid content (SLC) of head rice kernels] to match end-user specifications; this prompts the question as to whether the SLC level significantly impacts milled rice fissuring rates. Additionally, Siebenmorgen et al. (1998) found that thicker kernels were more likely to fissure than thinner kernels, suggesting that kernel thickness plays a role in determining fissure occurrence. Thus, the objectives of this study were to elucidate the effects of DOM and rice kernel thickness on milled rice fissuring rates.

PROCEDURES

The pure-line cultivar CL151, and the hybrid cultivar CLXL745, both long-grains, were combine-harvested from Harrisburg and Pocahontas, Ark., respectively, at MCs of 18.5% to 21% in 2012. For each cultivar lot, ~10 kg (22 lb) of rough rice was cleaned using a grain cleaner/tester (MCI® Kicker Grain Tester, Mid-Continent Industries, Inc., Newton, Kan.), then placed in screen-bottomed trays and gently dried to 12 ± 0.5% MC in a conditioning chamber (Model AA - 558, Parameter Generation & Control Inc., Black Mountain, N.C.) where temperature and RH were maintained at 25 °C (77 °F) and 56% RH, respectively.

A preliminary milling investigation was conducted in which duplicate, 150 g (5.3 oz) rough rice subsamples from each cultivar lot were dehulled using a laboratory huller (THU-35A, Satake Engineering Co., Ltd., Tokyo, Japan) and milled for 10, 20, 30, or 45 s using a laboratory mill (McGill No. 2, Rapsco, Brookshire, Texas) with a 1.5 kg (3.3 lb) weight placed on the lever arm 15 cm (6 inches) from the center of the milling chamber. Head rice was separated from the broken kernels using a sizing device (Grain Machinery Manufacturing Co., Miami, Fla.). Head rice SLC was measured by scanning ~50 g (1.76 oz.) of intact, head rice kernels using near-infrared-reflectance

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[1] Unless otherwise specified, all moisture contents are reported on a wet-basis.

(NIR, Model DA7200, Perten Instruments, Hägersten, Sweden), with a calibration described by Saleh et al. (2008). For each cultivar lot, the SLC was then plotted as a function of milling duration and the milling durations required to reach SLC levels of 0.2%, 0.4%, 0.6%, and 0.8% were determined using interpolation. Subsequently, additional subsamples from each cultivar lot were milled to the required durations to attain the desired SLC levels.

To measure fissuring rates, head rice was exposed to air at a temperature of 30 °C (86 °F) and RHs of 20% and 80%; these air temperature/RH conditions were maintained in a chamber (Platinous Sterling Series T and RH Chamber, ESPEC North America, Hudsonville, Mich.) wherein temperature and RH are automatically controlled. Inside the ESPEC, a 'turn-table' apparatus with 16 sample holders was placed to rotate under a recording video camera. Built in fiber optic lights were used to help detect fissures. Images were taken every 4 min and recorded. A detailed description of the apparatus can be found in Siebenmorgen et al. (2009).

Twenty-five, non-fissured, non-chalky head rice kernels of random thicknesses from each cultivar lot/SLC combination were placed in sample holders on the turn-table and fissures were enumerated at 4, 8, 16, 32, 60, and 120 min of exposure from the recorded images. Kernels having at least one fissure were enumerated and were expressed as a number percentage of the 25 head rice kernels in each sample holder. Thus, the full-factorial design (2 cultivar lots × 2 RHs × 4 SLCs × 6 exposure durations × 4 replications) yielded a total of 384 experimental observations for the SLC-fissure kinetics study.

To investigate the effect of kernel thickness on rate of fissuring, samples from both cultivar lots were milled to 0.4% SLC and head rice was separated from the broken kernels. Head rice kernel thicknesses of triplicate subsamples of 100 randomly selected head rice kernels were measured using a rice image analyzer (RIA 1A, Satake, Hiroshima, Japan). Both cultivar lots had the same mean head rice kernel thickness of 1.71 mm (0.067 inch) and the same standard deviation of 0.11 mm (0.004 inch). A sufficient number of head rice kernels were passed through the image analyzer, which divided the kernels into 14 fractions based on thickness. These head rice kernels were then grouped into three thickness fractions, namely, thin <1.66 mm (< 0.065 inch), medium 1.66 to 1.80 mm (0.065 inch to 0.071 inch), and thick >1.80 mm (> 0.071 inch). The experimental setup, exposure air temperature/RH conditions and exposure durations used, were the same as mentioned above. Hence, a full-factorial design resulted in 288 experimental observations (2 cultivar lots × 2 RHs × 3 thickness fractions × 6 exposure durations × 4 replications) to evaluate the effects of kernel thickness on fissure kinetics. All statistical analyses were performed using JMP® v. 11.0.0 Pro software (SAS Institute, Inc., Cary, N.C.).

RESULTS AND DISCUSSION

Figure 1 shows fissured kernel percentages (FKPs), as a function of exposure duration, for cultivar lots CL151 and CLXL745 exposed to air at a temperature of 30

°C and RHs of 20% (rapid moisture-desorption environment) and 80% (rapid moisture-adsorption environment). Fissuring rates generally increased with DOM level (decreasing SLC values), with this effect being more pronounced at the 80% RH environment. At this air condition, fissuring rates among SLC levels varied for both the cultivar lots. Rice milled to 0.2% SLC (greater DOM) fissured the most, whereas rice milled to 0.8% SLC (lesser DOM) fissured the least. However, at the 20% RH condition, all SLC-curves of cultivar lot CL151 were practically indistinguishable; whereas those of cultivar lot CLXL745 showed that fissuring rates slightly increased with decreasing SLC.

Both cultivar lots fissured much faster at the 20% RH setting as compared to the 80% RH environment (Fig. 1); this trend was seen across SLC levels. Almost all the kernels of cultivar lot CL151 were fissured after ~16 min of exposure to the 20% RH air, regardless of SLC levels. For the same air condition, most of the kernels of cultivar lot CLXL745 were fissured after ~32 min, but the fissuring rate was slightly different among SLC levels, with kernels milled to lesser SLCs fissuring faster than those milled to greater SLCs.

At the 80% RH setting, the fissuring rate decreased considerably for both cultivars relative to the 20% RH condition (Fig. 1). After 16 min of exposure to 80% RH air, 30% of the CL151 kernels milled to 0.2% SLC were fissured whereas only 4% of the kernels milled to 0.8% SLC were fissured. In the case of CLXL745 for the same 16 min exposure duration, 45% of the kernels milled to 0.2% SLC were fissured, whereas 15% of the kernels milled to 0.8% SLC were fissured.

Means were separated using Tukey's Honestly Significant Difference (HSD) method to test for significant differences in FKPs among cultivar lot/RH/SLC combinations (Table 1). At the 20% RH condition, for both cultivar lots, there were only a few exposure durations in which significant differences in FKPs due to SLC were found, as indicated by the letters A-D in Table 1. At exposure duration of 4 min, kernels of CL151 milled to 0.2% SLC fissured significantly more than those milled to 0.6% and 0.8% SLC; but FKP of kernels milled to 0.4% SLC were not significantly different from those milled to 0.2%, 0.6%, or 0.8% SLC. Fissured kernel percentages of CL151 kernels milled to different SLC levels were not significantly different for the 8, 16, 32, 60, and 120 min exposure durations. At the same air condition, CLXL745 showed no significant differences in FKPs at exposure durations of 4, 32, 60, and 120 min. At exposure durations of 8 min and 16 min, CLXL745 kernels showed a trend of increasing FKPs as SLC decreased, but there were statistical differences only between kernels milled to 0.8% SLC and kernels milled to all other SLC levels.

At the 80% RH condition, there were significant increases in FKPs as SLC decreased for both cultivars; this was observed for all exposure durations beyond 8 min (Table 1). Trends of increasing FKPs with decreasing SLCs were clearly evident, with varying degrees of statistical differences among SLC levels across exposure durations. For an exposure duration of 120 min, CL151 and CLXL745 milled to each SLC level had significantly different FKPs, with 0.2% SLC samples fissuring the most and 0.8% SLC samples fissuring the least.

Tukey's HSD analyses were used to test for significant differences in FKPs among cultivar lot/RH/thickness combinations. As with the SLC evaluation, fissuring rates were very high for the 20% RH condition for all three thickness fractions (data not shown). There were no significant differences among FKPs with varying kernel thicknesses for kernels exposed to the 20% RH setting for the entire exposure duration range for both cultivars. This finding was also observed for CLXL745 kernels exposed to 80% RH air. The finding also held true for CL151 kernels exposed to 80% RH air for all exposure durations except at 16, 32, and 60 min; for these, FKPs for thin kernels were significantly greater than those observed for the medium and thick kernels, a finding contradicting previous studies wherein thick kernels showed a greater propensity to fissuring than thinner kernels. But even in these cases, the differences in FKPs were not practically significant, leading to the conclusion that kernel thickness of head rice did not affect fissuring rates in both the rapid moisture-desorption environment (10% RH) as well as in the rapid moisture-adsorption environment (80% RH).

SIGNIFICANCE OF FINDINGS

This study confirms that kernel fissuring can occur very rapidly, corroborating previous research using past cultivars. Moreover, a rapid moisture-desorption environment generally caused greater fissuring rates as compared to a rapid moisture-adsorption environment; the same trend was observed at 10% RH versus 90% RH by Siebenmorgen et al. (2009). Milling rice to various DOMs impacted the rates of fissuring with fissuring rates being directly related to DOM. However, the impacts on fissuring rate from DOM differences were overshadowed by those resulting from environmental conditions. Kernel thickness did not appreciably impact fissuring rates in either the rapid moisture-desorption or moisture-adsorption environments used in this study.

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Table 1. Comparisons of fissured kernel percentages of head rice kernels for the given exposure durations, against surface lipid content (SLC), relative humidity (RH), and cultivar lots. Comparisons are valid within a cultivar/RH/exposure duration set at an air temperature of 30 °C (86 °F).

			Exposure duration at 30 °C					
Cultivar lot	RH	SLC	4 min	8 min	16 min	32 min	60 min	120 min
	------- (%) ------		------- [Least square mean of fissured kernels (%)[†]]---------					
CL151	20	0.2	64 A[‡]	96	100	100	100	100
		0.4	58 AB	94	100	100	100	100
		0.6	53 B	93	100	100	100	100
		0.8	47 B	91	100	100	100	100
	80	0.2	7	12	27 A	52 A	66 A	80 A
		0.4	4	8	11 AB	33 B	50 B	73 B
		0.6	1	6	8 B	26 B	40 C	61 C
		0.8	0	4	6 B	23 B	35 C	47 D
CLXL745	20	0.2	11	50 A	96 A	100	100	100
		0.4	12	42 A	95 A	100	100	100
		0.6	10	38 A	90 A	99	100	100
		0.8	5	22 B	67 B	93	98	100
	80	0.2	8	16	41 A	82 A	93 A	99 A
		0.4	3	14	37 A	56 B	84 B	91 B
		0.6	1	9	18 B	45 BC	61 C	77 C
		0.8	1	7	17 B	43 C	52 D	60 D
		HSD	10	14	19	11	6	5

[†] Least square means within a cultivar/RH/exposure duration set followed by the same letter are not significantly different at $P = 0.05$.

[‡] Data sets with statistically significant differences are indicated by letters.

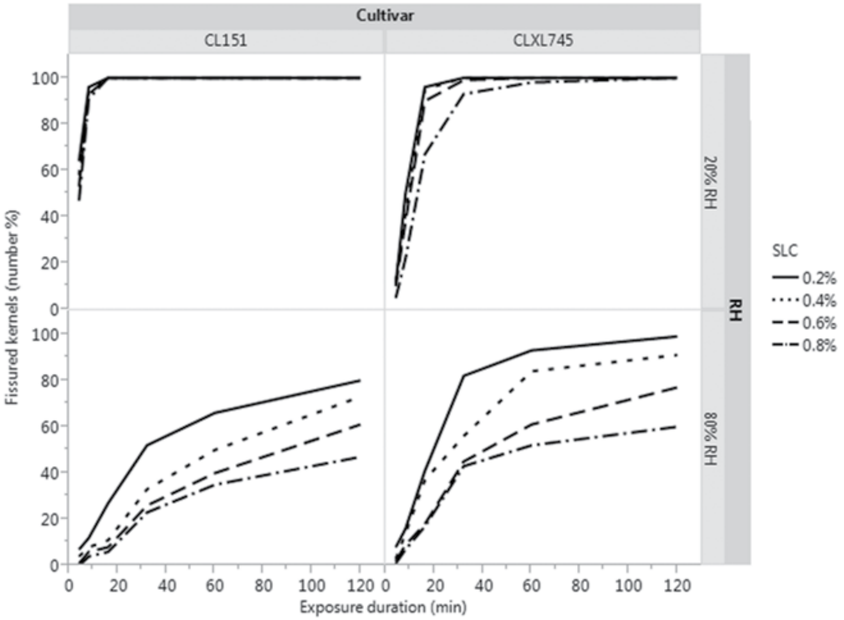

Fig. 1. Fissured kernel percentage as a function of exposure duration for cultivar lots CL151 and CLXL745 when exposed to air at a temperature of 30 °C (86 °F) and relative humidities (RHs) of 20% and 80%. Exposure durations comprised 4, 8, 16, 32, 60, and 120 min. The various curves represent surface lipid contents (SLCs) of 0.2, 0.4, 0.6, and 0.8%. Curves are based on data representing the mean values of four replications.

Milled Rice Fissuring Rates of Pure-Line and Hybrid Cultivar Lots

S. Mukhopadhyay and T.J. Siebenmorgen

ABSTRACT

Fissuring induced by rapid moisture adsorption or desorption in milled rice results in substantial financial losses owing to reduced performance in end-use processing operations. This study investigated the rates of fissuring of head rice of three hybrid, long-grain (H-L) cultivar lots, three pure-line, long-grain (P-L) cultivar lots, and two pure-line, medium-grain (P-M) cultivar lots, when exposed to different air temperature/relative humidity/exposure duration combinations. Samples from all eight cultivar lots were milled to a common degree of milling. Non-fissured, non-chalky, head rice kernels were exposed to air temperatures of 10 °C (50 °F) and 30 °C (86 °F) and relative humidities (RHs) of 10%, 20%, 50%, 80%, and 90% for 4, 8, 16, 32, 60, and 120 min. The hybrid cultivar lots required shorter milling durations than the pure-lines; and in general, long-grain cultivar lots required shorter milling durations than medium-grain cultivar lots to reach the desired degree of milling. Fissured kernel percentages (FKPs) were greater when head rice was exposed to an air temperature of 30 °C (86 °F) as compared to that at 10 °C (50 °F). At both exposure temperatures, FKPs were greater at extreme RHs (10%, 20%, or 90%) and it was found that the effect of RH was more pronounced than the effect of temperature. On comparing FKPs within a temperature/exposure-duration set, it was found that the P-M cultivar group fissured more than either the P-L or H-L cultivar groups, where statistically significant differences were detected. Regardless of exposure conditions, no statistically significant differences in FKPs were detected between P-L and H-L cultivar groups.

INTRODUCTION

Fissuring in milled rice kernels can occur when low moisture content (MC) kernels (less than approximately14%[1]) are exposed to rapid moisture-adsorption environments or high MC kernels are exposed to rapid moisture-desorption environments, thus causing substantial financial losses to post-milling processors in terms of product waste and throughput limitations (Siebenmorgen et al., 2009). Rapid moisture transfer, in either direction, between a kernel and its surrounding environment, leads to the development of intra-kernel stresses, and fissuring occurs when these stresses exceed the tensile strength of the kernel. Lloyd and Siebenmorgen (1999) demonstrated that high MC rice was more susceptible to fissuring when exposed to low relative humidities (RHs), and vice-versa. Siebenmorgen et al. (2009) reported that temperature played a much lesser, though significant, role in that the rate of fissuring was directly related to temperature increase.

Milled rice fissuring and breakage resulting from various post-milling air environments were reported by Siebenmorgen et al. (1998) for long-grain varieties and by Lloyd and Siebenmorgen (1999) for medium-grain varieties. Over the past decade, there has been a dramatic increase in hybrid rice cultivation in the United States because of greater crop yields and improved disease resistance offered by hybrid cultivars over pure-line cultivars. Limited research has addressed milled rice fissure kinetics on current pure-line and hybrid, long-grain and medium-grain cultivars of the mid-South. Hence, the objective of this study was to compare the fissuring rates of head rice of current cultivars at different air temperature/RH/exposure duration combinations.

PROCEDURES

Three hybrid, long-grain (H-L) cultivar lots (CLXL745, CLXL729, and XL753), three pure-line, long-grain (P-L) cultivar lots (CL151, Wells, and Cheniere), and two pure-line, medium-grain (P-M) cultivar lots (Jupiter and CL261) were combine-harvested at Arkansas locations, at MCs of 18.5% to 21% in 2012, with the exception of CL261, which was harvested in 2011. For each cultivar lot, ~ 10 kg (22 lb) of rough rice was cleaned using a grain cleaner/tester (MCI® Kicker Grain Tester, Mid-Continent Industries, Inc., Newton, Kan.), then placed in screen-bottomed trays and gently dried to 12 ± 0.5% MC in a conditioning chamber (Model AA - 558, Parameter Generation & Control Inc., Black Mountain, N.C.) where temperature and RH were maintained at 25 °C (77 °F) and 56% RH, respectively.

A preliminary milling investigation was conducted in which duplicate, 150 g (5.3 oz) rough rice subsamples from each cultivar lot were dehulled using a laboratory huller (THU-35A, Satake Engineering Co., Ltd., Tokyo, Japan) and milled for 10, 20, 30, or 45 s using a laboratory mill (McGill No. 2, Rapsco, Brookshire, Texas) with a 1.5 kg (3.3 lb) weight placed on the lever arm 15 cm (6 inches) from the center of the milling chamber. Head rice was separated from the broken kernels using a sizing device

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[1] Unless otherwise specified, all moisture contents are reported on a wet-basis.

(Grain Machinery Manufacturing Co., Miami, Fla.). Head rice surface lipid content (SLC), which is a measure of the degree of milling (DOM), was measured by scanning ~ 50 g (1.76 oz.) of intact head rice kernels using near infrared reflectance (NIR, Model DA7200, Perten Instruments, Hägersten, Sweden), with a calibration described by Saleh et al. (2008). For each cultivar lot, the SLC was then plotted as a function of milling duration and the milling durations required to reach an SLC level of 0.4% was determined using interpolation. Subsequently, additional subsamples from each cultivar lot were milled to the required durations to attain 0.4% SLC.

To study milled rice fissure kinetics at different air temperature/RH conditions, samples from all eight cultivar lots were milled to 0.4% SLC and head rice was separated from the broken kernels. Head rice was subsequently exposed to air temperatures of 10 °C (50 °F) and 30 °C (86 °F) and to RHs of 10%, 20%, 50%, 80%, and 90%; these air temperature/RH conditions were maintained in a chamber (Platinous Sterling Series T and RH Chamber, ESPEC North America, Hudsonville, Mich.) wherein temperature and RH are automatically controlled. Inside the controlled environment chamber, a 'turn-table' apparatus with 16 sample holders was placed to rotate under a recording video camera. Built-in fiber optic lights were used to help detect fissures. Images were taken every 4 min and recorded. A detailed description of the apparatus can be found in Siebenmorgen et al. (2009).

Twenty-five, non-fissured, non-chalky head rice kernels were selected randomly from each cultivar lot and placed in sample holders on the turn-table. Fissures were enumerated from the recorded images at 4, 8, 16, 32, 60, and 120 min of exposure to a given air temperature and RH. Kernels having at least one fissure were enumerated; the total number of fissured kernels in each sample holder was expressed as a number percentage of the 25 head rice kernels in that sample holder. Thus, the full-factorial design (8 cultivar lots × 2 temperatures × 5 RHs × 6 exposure durations × 4 replications) yielded a total of 1,920 experimental observations for this study. All statistical analyses were performed using JMP® v. 11.0.0 Pro software (SAS Institute, Inc., Cary, N.C.).

RESULTS AND DISCUSSION

The millability curves of all the cultivar lots showed that SLC decreased approximately exponentially with milling duration (Fig. 1). Table 1 gives the milling duration for each cultivar lot required to achieve an SLC of 0.4%. Hybrid, long-grain cultivar lot CLXL729 required the shortest milling duration of 17 s; whereas P-M cultivar CL261 required the longest, that of 28 s. A difference in milling behavior between hybrid and pure-line cultivars was noted, with hybrids requiring shorter milling durations than the pure-lines, the exceptions being Wells and XL753 which were similar at 22 s; similar results were reported by Lanning and Siebenmorgen (2011). It was also seen that in general, long-grain cultivar lots required shorter milling durations (~17 to 25 s) than medium-grain cultivar lots (26 and 28 s, for Jupiter and CL261, respectively); corroborating previous research using past cultivars.

Figure 2 shows fissured kernel percentages (FKPs), at RHs of 10%, 20%, 50%, 80%, and 90%, for all eight cultivar lots grouped into three cultivar groups after being exposed to air at temperatures of 10 °C and 30 °C for 4 min. Figure 2 illustrates the general trend that FKPs were greater at 30 °C as compared to that at 10 °C. Least Square Means were analyzed using Tukey's Honestly Significant Difference (HSD) method to test for statistically significant differences in FKP within an air temperature/RH set across cultivar lots for the 4 min exposure duration (Table 2). At the 10 °C condition, FKPs were greatest at 10% RH, with FKPs of CLXL745, Cheniere, and CL261 being the greatest; FKPs of these three cultivars were significantly greater than those of Jupiter, which was similar to all other cultivar lots. However, at the 10 °C/20% RH setting, Jupiter fissured significantly greater than all the other cultivar lots.

Kernels of all cultivar lots fissured to various extents after 4 min when exposed to air at 30 °C at RHs of 10%, 20%, and 90%; differences in FKPs among the cultivar lots were evident at these RH levels (Table 2). At the 30 °C/10% RH setting, there were significant differences in FKPs, CL261 had the greatest FKPS while Wells had the least. However, at 20%, 50%, 80%, and 90% RH conditions at the same temperature, FKPs of kernels of the various cultivar lots were not significantly different from each other.

Figure 3 illustrates FKPs, at exposure durations of 4, 8, 16, 32, 60, and 120 min, for the H-L (CLXL745, CLXL729, and XL753), P-L (CL151, Wells, and Cheniere), and P-M (Jupiter and CL261) cultivar groups after being exposed to air temperatures of 10 °C and 30 °C, and RHs of 10% and 90%. At the 10 °C condition, kernels fissured at a much lesser rate at 90% RH exposure compared to that at 10% RH. Additionally, almost all kernels were fissured after 32 min of exposure at the 10 °C/10% RH environment but at the 90% RH setting at the same temperature, FKPs were much less. At the higher temperature of 30 °C, the rate of fissuring was much greater, regardless of RH, with the 30 °C/10% RH condition producing the most extreme fissuring rates. At 30 °C/10% RH, almost all kernels across cultivar groups were fissured after 8 min of exposure; but at 90% RH, this happened only beyond 32 min of exposure.

Figure 4 shows the same illustration as in Figure 3, except that the RH levels displayed here are 20% and 80%. At 10 °C, FKPs were greater at the 20% RH than that at 80% RH. At 10 °C/20% RH, all kernels fissured after 120 min of exposure; whereas at 10 °C/80% RH, only ~30% of the P-M kernels, ~8% of the P-L kernels, and ~10% of the H-L kernels fissured. At 30 °C, almost all kernels were fissured after 8 min of exposure at 20% RH, but at 80% RH FKPs never exceeded 15%. The P-M cultivar group had consistently greater FKPs than the P-L and H-L cultivar groups at both temperatures and both RH levels, except at 30 °C/20% RH when they were similar. Thus, medium-grain kernels generally fissured more than long-grains under similar sets of moisture adsorption as well as desorption conditions. These findings corroborate previous research, suggesting that kernel thickness has an impact on the extent of fissuring.

Tukey's HSD analyses were used to test for differences in FKP among cultivar-groups within each air temperature/exposure duration combination (Table 3). It appeared that the P-M cultivar group fissured more than either the P-L or H-L cultivar groups, where statistically significant differences were detected. Regardless of exposure conditions, no statistically significant differences in FKPs were detected between P-L and H-L cultivar groups.

It was interesting to note the difference in fissure patterns of kernels exposed to the moisture desorption and moisture adsorption environments. Figure 5 (a) and (b) illustrate a head rice kernel exposed to low RH (10% RH) and high RH (90% RH) for 90 min. Kernels that were fissured when exposed to the low-RH environment (10% RH) displayed many ‘zig-zag/jagged’, surface fissures (this type of fissure pattern is also known as ‘turtle-back’ fissuring); whereas kernels that were exposed to the high-RH environment (90% RH), displayed distinct ‘cross-wise’ fissures. During rapid adsorption, moisture enters the kernel surface, resulting in the swelling and expansion of the outer layers of the kernel. Since, moisture has not diffused to the kernel interior, the inner layers of the kernel do not expand to the same degree as the surface; this leads to the development of stress gradients inside the kernels that ultimately leads to fissure formation, with fissures initiating at the kernel core. However, with desorption, moisture is evaporated from the surface of the kernel very rapidly, but moisture from the core of the kernel diffuses toward the outer layers at a much slower rate. This rapid drying of the surface relative to the kernel core again creates stress differentials resulting in fissures initiating at the kernel surface in a generally irregular pattern.

SIGNIFICANCE OF FINDINGS

This study confirms that kernel fissuring can occur very rapidly, and that present cultivars, both pure-lines and hybrids, respond to environmental conditions in much the same way as reported for past cultivars. Additionally, medium-grain kernels generally fissured more than long-grain kernels under similar sets of moisture adsorption as well as desorption conditions. Moreover, rapid moisture desorption environments were found to generally cause greater fissuring rates compared to rapid moisture adsorption environments; the same trend was observed by Siebenmorgen et al. (2009). This study showed that the effect of air RH was more pronounced than that of air temperature. However, air temperature did play a significant role, in that across RH levels, the extent of kernel fissuring was directly related to air temperature. This research showed that extreme levels of fissured kernels can be produced by relatively short exposures to air with either high or low RHs and that these levels are increased with increasing air temperatures.

ACKNOWLEDGMENTS

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Table 1. Milling durations required to reach a head rice surface lipid content (SLC) of 0.4% for the indicated cultivar lots.

Cultivar type	Cultivar	Milling duration[†]
		(s)
Pure-line long-grain	CL151	25
	Cheniere	24
	Wells	22
Hybrid long-grain	CLXL745	18
	CLXL729	17
	XL753	22
Pure-line medium-grain	Jupiter	26
	CL261	28

[†] Samples were milled using a laboratory mill (McGill No. 2, Rapsco, Brookshire, Texas).

Table 2. Comparisons of fissured kernel percentages of head rice kernels exposed to air at 10 °C and 30 °C, and relative humidities of 10%, 20%, 50%, 80%, and 90% for 4 min.[†]

		Relative humidity (%)				
Air temperature	Cultivar lot	10	20	50	80	90
(°C)		------Least square mean of fissured kernels[‡] (%)------				
10	CLXL745	28 AB[§]	0 B	0	0	0
	CLXL729	16 C	0 B	0	0	0
	XL753	14 C	0 B	0	0	0
	CL151	16 C	0 B	0	0	0
	Wells	14 C	0 B	0	0	0
	Cheniere	36 A	0 B	0	0	0
	Jupiter	20 BC	2 A	0	0	0
	CL261	38 A	0 B	0	0	0
	HSD	11	2	0	0	0
30	CLXL745	79 ABC	58	0	0	17
	CLXL729	74 BC	68	0	0	20
	XL753	71 C	71	0	0	14
	CL151	74 BC	59	0	0	18
	Wells	67 C	56	0	0	11
	Cheniere	86 ABC	72	0	0	6
	Jupiter	92 AB	70	0	0	29
	CL261	95 A	71	0	0	17
	HSD	21	23	0	0	26

[†] Comparisons are valid within a temperature/RH set across cultivar lots.

[‡] Least square means within a temperature/RH set across cultivar lots followed by the same letter are not significantly different at $P = 0.05$.

[§] Data sets with statistically significant differences are indicated by letters.

Table 3. Comparisons of fissured kernel percentages of head rice kernels exposed to air at 10 °C and 30 °C, and relative humidities of 10%, 20%, 50%, 80%, and 90% for 4, 8, 16, 32, 60, and 120 min.[†]

Exposure	Cultivar	Relative humidity (%) at 10 °C					Relative humidity (%) at 30 °C				
duration	group	10	20	50	80	90	10	20	50	80	90
(min)											
4	H-L[‡]	19 B[§]	0 C	0 C	0 C	0 C	75 B	59 C	0 F	0 F	17 D
	P-L	22 B	0 C	0 C	0 C	0 C	76 B	62 C	0 F	0 F	12 DE
	P-M	29 A	1 C	0 C	0 C	0 C	94 A	71 BC	0 EF	0 EF	23 D
8	H-L	47 A	1 B	0 B	0 B	4 B	97 A	100 A	0 D	0 D	40 C
	P-L	57 A	4 B	0 B	0 B	4 B	100 A	100 A	0 D	0 D	45 BC
	P-M	57 A	7 B	0 B	0 B	3 B	100 A	100 A	0 D	0 D	53 B
16	H-L	68 A	24 B	0 C	2 C	6 C	100 A	100 A	0 D	2 D	84 C
	P-L	75 A	34 B	0 C	4 C	5 C	100 A	100 A	0 D	2 D	91 B
	P-M	74 A	36 B	0 C	3 C	8 C	100 A	100 A	0 D	6 D	97 AB
32	H-L	98 A	51 C	0 E	3 E	25 D	100 A	100 A	0 D	3 C	98 A
	P-L	97 A	57 C	0 E	6 E	25 D	100 A	100 A	0 D	4 C	100 A
	P-M	96 A	74 B	0 E	6 E	33 D	100 A	100 A	0 D	8 B	100 A
60	H-L	100 A	80 C	0 G	8 FG	58 E	100 A	100 A	0 E	4 D	100 A
	P-L	100 A	90 B	0 G	10 F	69 D	100 A	100 A	0 E	6 C	100 A
	P-M	100 A	93 B	0 G	18 F	74 CD	100 A	100 A	0 E	13 B	100 A
120	H-L	100 A	99 A	0 E	10 D	90 B	100 A	100 A	0 D	5 C	100 A
	P-L	100 A	100 A	0 E	12 D	96 A	100 A	100 A	0 D	7 C	100 A
	P-M	100 A	100 A	0 E	30 C	98 A	100 A	100 A	0 D	16 B	100 A

[†] Comparisons are valid within a temperature/exposure-duration set across cultivar groups.

[‡] H-L, P-L, and P-M represent hybrid long-grain (CLXL729, CLXL745, and XL753), pure-line long-grain (CL151, Wells, and Cheniere), and pure-line medium-grain (CL261 and Jupiter) cultivar lots, respectively.

[§] Least square means within a temperature/exposure duration set across cultivar groups followed by the same letter are not significantly different at *P* = 0.05. Data sets with statistically significant differences are indicated by letters.

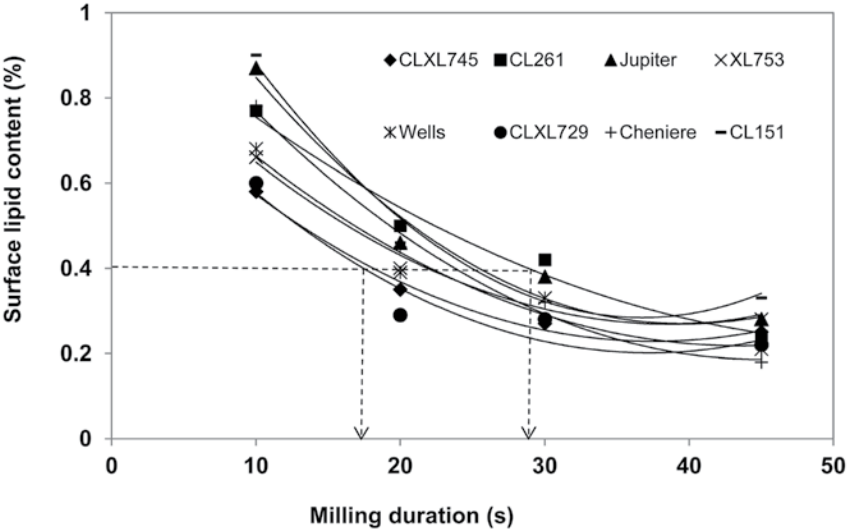

Fig. 1. Head rice surface lipid content (SLC) versus milling duration data for the indicated cultivar lots milled for 10, 20, 30, and 45 s, using a McGill No. 2 laboratory mill. Each data point represents the mean value of duplicate SLC readings. Curves were developed using a quadratic model. The dashed lines illustrate the procedure to determine the milling duration required to achieve an SLC of 0.4%; for cultivar lot CLXL729, the duration is illustrated to be 17 s, while for CL261, the duration is 28 s.

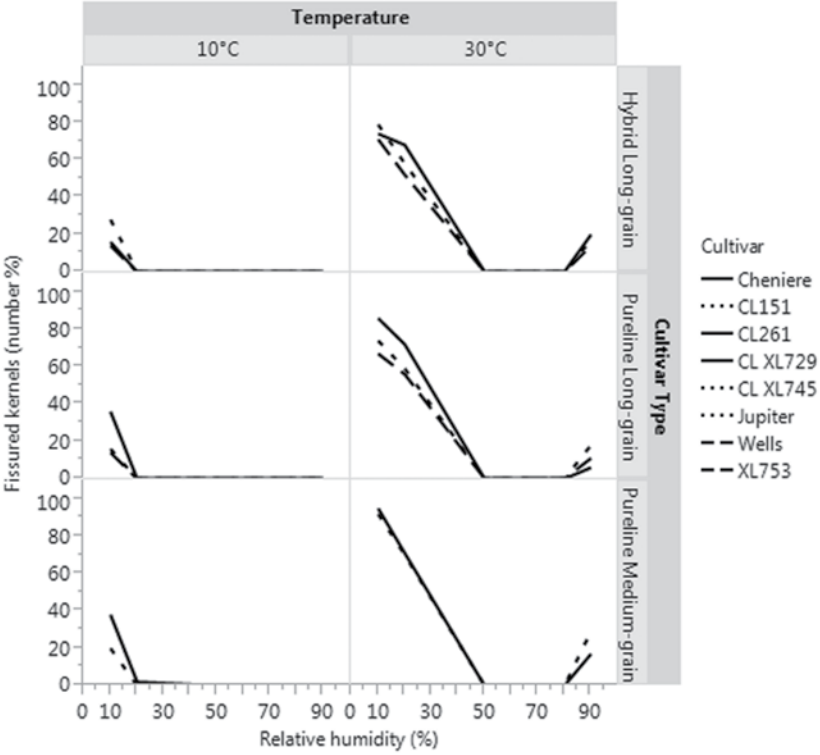

Fig. 2. Fissured kernel percentages at relative humidities of 10%, 20%, 50%, 80%, or 90% for the indicated cultivar lots when exposed to air at temperatures of 10 °C and 30 °C for 4 min. The data are categorized into three cultivar groups: hybrid long-grain (CLXL729, CLXL745, and XL753), pure-line long-grain (CL151, Wells, and Cheniere), and pure-line medium-grain (CL261 and Jupiter). Curves are based on data representing the mean values of four replications.

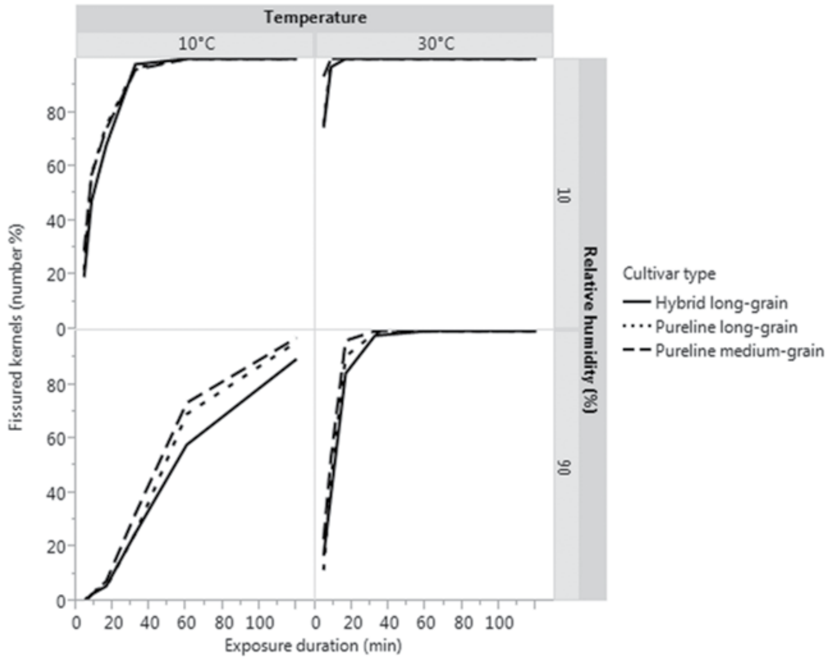

Fig. 3. Fissured kernel percentages at exposure durations of 4, 8, 16, 32, 60, and 120 min for the indicated cultivar lots when exposed to air at temperatures of 10 °C and 30 °C and relative humidities of 10% and 90%. The data are categorized into three cultivar groups: hybrid long-grain (CLXL729, CLXL745, and XL753), pure-line long-grain (CL151, Wells, and Cheniere), and pure-line medium-grain (CL261 and Jupiter). Curves are based on data representing the mean values of four replications.

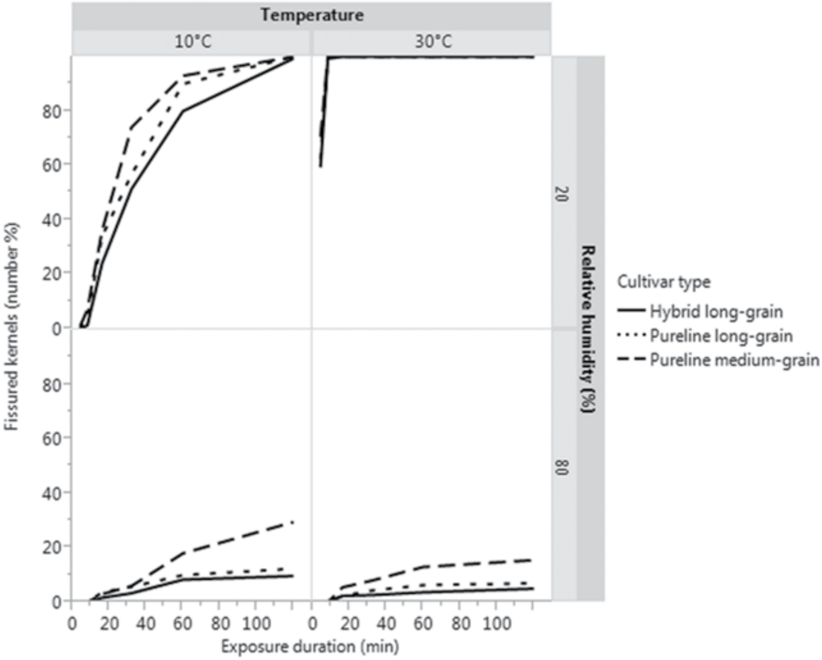

Fig. 4. Fissured kernel percentages at exposure durations of 4, 8, 16, 32, 60, and 120 min for the indicated cultivar lots when exposed to air at temperatures of 10 °C and 30 °C and relative humidities of 20% and 80%. The data are categorized into three cultivar groups: hybrid long-grain (CLXL729, CLXL745, and XL753), pure-line long-grain (CL151, Wells, and Cheniere), and pure-line medium-grain (CL261 and Jupiter). Curves are based on data representing the mean values of four replications.

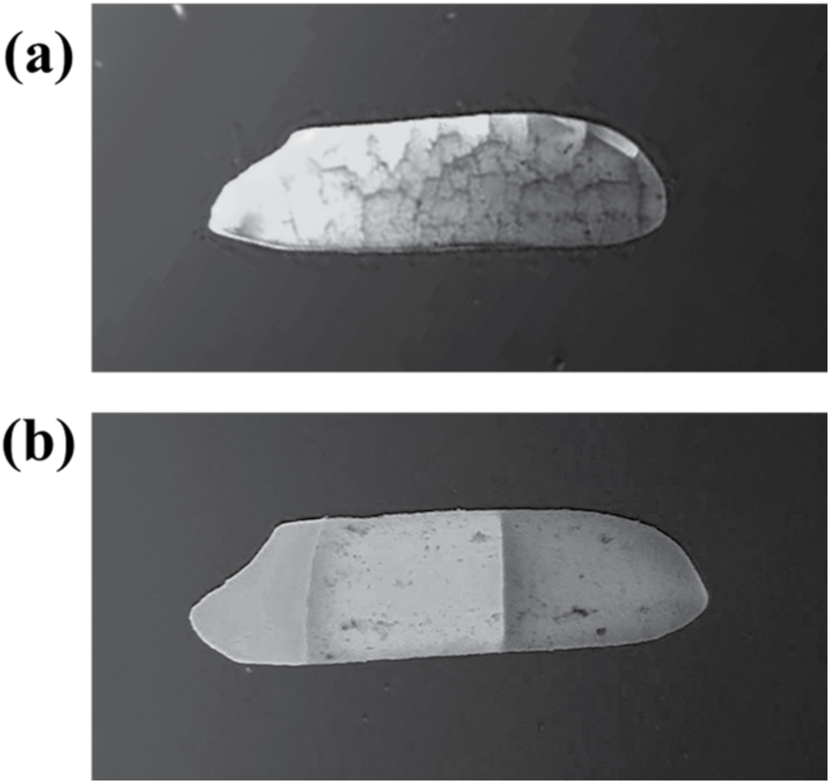

Fig. 5. (a) A head rice kernel that fissured when exposed to a rapid moisture-desorption environment (10% RH) and (b) to a rapid moisture-adsorption environment (90% RH). Both images were taken after the head rice was exposed to air at 30 °C for 90 min.

Exploring Rice Quality Traits of Importance to Export Markets

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ABSTRACT

The quality attributes of twenty milled rice samples from Arkansas (ARK), Asia (ASA), and South America (SAM) were examined to better understand the factors of key importance to rice export markets. All SAM samples were distinguished from the rest by their noticeably lower percent chalk, whiteness (L*), whiteness/yellowness ratio (L*/b*), and gelatinization temperature. Both percent chalk and gelatinization temperature significantly correlated with starch fine structures; negatively with percent amylopectin short chains (A chains), and positively with amylopectin long chains (B3+ chains) and average chain length. Whiteness showed significant correlation with protein content (negative) and some amylopectin structures. Yellowness correlated with total mineral content (positive) and also with some amylopectin structures. Present findings have shown the importance of amylopectin structure to rice quality.

INTRODUCTION

United States rice has long been reputed as being the world's quality standard for long-grain rice. In recent years, however, the industry has been faced with unfavorable quality issues raised by both domestic and international customers. It is critical to understand the rice quality traits important to the export markets for the U.S. rice industry to remain globally competitive. In relation to consumer demand and international trade, rice quality is influenced by genetic and environmental factors (Juliano, 1990). An important criterion that most consumers consider in purchasing milled rice is its appearance, which comprises chalkiness, color, translucency, and grain size and shape (Juliano, 1990). Milled rice translucency improves, whereas whiteness decreases with late nitrogen fertilizer application (Perez et al., 1996). Elevated nighttime air temperatures during kernel development unfavorably affect head rice chalkiness and color (Lanning et al., 2011; Lanning and Siebenmorgen, 2013). Compounding the environmental factors are new approaches of plant breeding that may potentially result in rice cultivars with diverse quality traits.

The purpose of this research is to seek insights into the factors related to starch fine structure and other endosperm chemical constituents that impact the quality of milled rice from various regions of the world.

PROCEDURES

Rice Samples

Milled rice samples consist of five premium quality, commercially milled samples from South America (SAM; Brazil and Peru); three commercially milled (Thailand Jasmine, Vietnam Jasmine, and Indian Basmati) and six laboratory milled samples from Asia (ASA); and six laboratory milled samples from Arkansas (ARK; CL151, CLXL745, and Taggart; one set of each cultivar from the 2011 and 2012 crop). The ARK samples were milled in the laboratory to a target surface lipid content of 0.4%, head rice was separated from broken kernels using a double tray shaker, and an atomizer was used to remove residual bran. The samples from SAM and ASA were from the 2012 crop. The exact milling history of the commercially milled samples was unknown. Commercial mills may employ polishing/grading/sorting practices to milled rice that could produce differences in appearance. Samples were kept in tightly sealed plastic jars and stored at room temperature prior to the tests.

Physical Qualities

Chalk measurements were performed on duplicate, 100 kernel brown rice samples using an image analysis system (WinSeedle Pro 2005a™, Regent Instruments, Quebec, Canada). Head rice color was measured by the L*a*b* color space principle using a colorimeter (ColorFlex, Hunter Associates Laboratory, Reston, Va.). The color indices L* (black to white), a* (green to red), and b* (blue to yellow) were measured simultaneously; however, only L* and b* are important to milled rice color. Surface lipid content was determined using a lipid extraction system (Soxtec Avanti 2055, Foss North America, Eden Prairie, Minn.) according to AACC method 30-20 (AACC International, 2000), with modifications by Matsler and Siebenmorgen (2005). Kernel dimensions (length, width, and thickness) were measured on 100 kernels using a Satake image analysis system (RIA 1A, Hiroshima, Japan).

Chemical Components

Milled rice flour samples were obtained by grinding in a laboratory mill (cyclone sample mill, Udy Corp., Ft. Collins, Colo.) to pass through a 0.5 mm sieve. Apparent amylose content was determined by iodine colorimetry; moisture content by oven-drying method; total protein by microkjeldahl method; and mineral content by dry-ashing method. Starch samples were prepared from milled rice flour by extraction with dilute alkali (0.1% NaOH) followed by lipid removal with water saturated n-butyl alcohol (Patindol and Wang, 2002). Amylopectin chain length distribution was characterized by high-performance anion exchange chromatography with pulsed amperometric detection (HPAEC-PAD) using isoamylase debranched starch samples.

Gelatinization and Pasting Characteristics

Milled rice flour gelatinization properties were assessed with a differential scanning calorimeter (DSC; Pyris Diamond, Perkin Elmer Instruments, Shelton, Conn.). Starch (~4.0 mg, dry basis) was weighed into an aluminum DSC pan, and 8 µL deionized water was added by a microsyringe. The mixture was hermetically sealed and equilibrated at room temperature for 1 hr before running the thermogram. Thermal scans involved heating the sample from 25 °C to 120 °C with a temperature increase rate of 10 °C/min. Flour pasting properties were determined with a Rapid Visco-Analyser (RVA model 4, Perten Instruments, Springfield, Ill.). Rice flour slurry was prepared by mixing 3.0 g of rice starch (12% moisture content basis) with 25.0 mL of deionized water in a canister. The slurry was heated from 50 °C to 95 °C at 3 °C/min, held at 95 °C for 10 min, cooled to 50 °C at 3 °C/min, and held at 50 °C for 10 min. The pasting properties measured included pasting temperature, peak viscosity, peak time, hot paste viscosity (trough), final viscosity, breakdown, setback, and total setback.

RESULTS AND DISCUSSION

The SAM samples were characterized by a minimal amount of chalkiness (0.0% to 0.3%) as measured by a WinSeedle Pro image analyzer. SAM samples also tended to have lower L* (whiteness) and greater b* (yellowness) values, whereas ARK samples tended to have greater L* and lower b* values. The L* values were 69.0 to 71.5, 69.8 to 73.8, and 71.5 to 75.4 for SAM, ASA, and ARK samples, respectively. The b* values were 16.4 to 18.1, 13.7 to 17.6, and 14.0 to 16.0 for SAM, ASA, and ARK samples, respectively. As a result, the L*/b* ratios for SAM were lower (3.6 to 4.4), as opposed to 4.9 to 5.2 for ARK and 4.0 to 5.3 for ASA. It should be noted, however, that the milling and post-milling history of the commercially milled samples were unknown. Commercial mills may employ polishing/grading/sorting practices on milled rice that could produce differences in appearance.

Correlation analysis showed that percent chalk was highly correlated with some amylopectin structural features, but not with amylose, protein, and mineral contents (Table 1). Whiteness showed significant negative correlation with protein content and some amylopectin structure characteristics (particularly A chains, B1 chains, and average chain length). Yellowness was positively correlated with total mineral content. Some amylopectin structural features also correlated with milled rice yellowness; A chains (positive), B1 chains (negative), and average chain length (negative).

Another remarkable quality trait associated with the SAM samples is their low gelatinization temperatures (Fig. 1), regardless of amylose content. Onset gelatinization temperature values were 59.8 to 64.3, 64.1 to 73.4, and 70.4 to 74.3 °C for SAM, ASA, and ARK samples, respectively. Table 2 indicates that gelatinization enthalpy properties significantly correlated with some amylopectin structural features, negatively with percent amylopectin short chains (A chains), and positively with amylopectin B1 chains and average chain length, but not with other milled rice components (amylose, protein, and minerals). Present findings are consistent with the literature that gelatinization properties are mainly affected by amylopectin fine structure (Wani et al., 2012).

None of the paste viscosity parameters measured using a Rapid Visco-Analyser consistently identified the SAM samples from the rest. Paste peak viscosity was 2608 to 3050, 2038 to 4254, and 1996 to 3231 centipoise for ARK, ASA, and SAM, respectively; whereas, paste final viscosity was 2884 to 3046, 3004 to 3918, and 3032 to 5126 centipoise, respectively. Results of correlations analyses indicate that peak viscosity negatively correlated with amylose and protein contents, but not with amylopectin structures (Table 3). Final viscosity positively correlated with amylopectin short chains (A chains) and negatively correlated with B1 chains and average chain length. The other paste viscosity parameters (breakdown, setback, and total setback) did not show significant correlation with any of the chemical components analyzed.

SIGNIFICANCE OF FINDINGS

Producing rice that can satisfy both domestic and export market demands is the key to a successful and competitive Arkansas rice industry. Findings from this research are useful to farmers in choosing specific cultivars to plant; to rice breeders in knowing the traits/markers to include in varietal improvement efforts; and to processors in making proper adjustments of existing processing operations so as to consistently produce high quality milled rice.

ACKNOWLEDGMENTS

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Table 1. Correlation coefficients for the relationship of milled rice appearance with chemical components and amylopectin fine structure.

Chemical component	Chalk (%)	Whiteness (L*)	Yellowness (b*)	L*/b*
Amylose content (%)	0.26	0.27	-0.22	0.27
Protein content (%)	-0.27	-0.54*	0.41	0.45*
Mineral content (%)	-0.19	-0.27	0.52*	-0.48*
Amylopectin structure				
A chains (%)[a]	-0.55*	-0.60**	0.61**	-0.67**
B1 chains (%)	0.41	0.51*	-0.56**	0.61
B2 chains (%)	0.05	0.10	0.02	-0.02
B3+ chains (%)	0.59**	0.34	-0.21	0.26
Average chain length	0.65**	0.59**	-0.48*	0.56*

* Significant at 95% probability ($P < 0.05$; n = 20).

**Significant at 99% probability ($P < 0.01$; n = 20).

[a] A chains, 6 to 12 glucose units; B1 chains, 13 to 24 glucose units; B2 chains, 25 to 36 glucose units; B3+ chains, ≥37 glucose units.

Table 2. Correlation coefficients for the relationship of milled rice gelatinization properties with chemical components and amylopectin fine structure.

Starch property	Gelatinization temperature Onset	Peak	Conclusion	Gelatinization range	Gelatinization enthalpy
Apparent amylose (%)	0.26	0.24	0.15	-0.33	-0.15
Total protein (%)	-0.19	-0.19	-0.18	0.03	-0.14
Total mineral (%)	-0.12	-0.10	-0.06	0.19	0.00
Amylopectin structure					
A chains (%)[a]	-0.92**	-0.94**	-0.92**	-0.07	-0.68**
B1 chains (%)	0.87**	0.87**	0.83**	-0.08	0.61**
B2 chains (%)	-0.23	-0.21	-0.14	0.28	-0.10
B3+ chains (%)	0.42	0.49*	0.53*	0.39	0.41
Average chain length	0.76**	0.81**	0.84**	0.31	0.63**

* Significant at 95% probability ($P < 0.05$; n = 20).

**Significant at 99% probability ($P < 0.01$; n = 20).

[a] A chains, 6 to 12 glucose units; B1 chains, 13 to 24 glucose units; B2 chains, 25 to 36 glucose units; B3+ chains, ≥37 glucose units.

Table 3. Correlation coefficients for the relationship of milled rice pasting properties with chemical components and amylopectin fine structure.

Starch property	Peak viscosity	Final viscosity	Paste breakdown	Setback viscosity	Total setback
Apparent amylose	-0.58**	0.00	-0.41	0.43	0.38
Total protein	-0.59**	-0.13	-0.50*	0.35	0.10
Total mineral	-0.15	-0.20	-0.04	-0.03	-0.11
Amylopectin structure					
A chains[a]	0.20	0.64**	-0.22	0.32	0.37
B1 chains	-0.31	-0.60**	0.11	-0.21	-0.28
B2 chains	0.44	0.11	0.21	-0.25	-0.23
B3+ chains	0.12	-0.28	0.31	-0.30	-0.21
Average chain length	0.02	-0.52*	0.34	-0.40	-0.38

* Significant at 95% probability ($P < 0.05$; n = 20).

**Significant at 99% probability ($P < 0.01$; n = 20).

[a] A chains, 6 to 12 glucose units; B1 chains, 13 to 24 glucose units; B2 chains, 25 to 36 glucose units; B3+ chains, ≥37 glucose units.

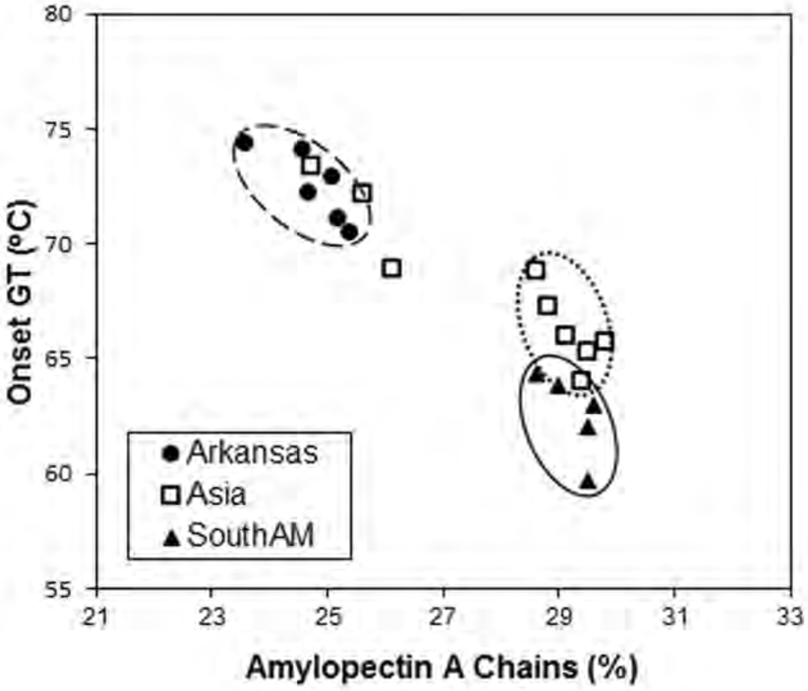

Fig. 1. A plot of gelatinization temperature (Onset GT) and percentage of amylopectin short chains (A chains) that differentiates the rice samples from Arkansas, Asia, and South America (SouthAM).

Commodity Program Options for Arkansas Farmers Under the Agricultural Act of 2014: Analysis of Arkansas Representative Panel Farms

E.C. Chavez, E.J. Wailes, and K.B. Watkins

ABSTRACT

With the expiration of the 2008 farm bill, the U.S. Agricultural Act of 2014 was finally passed and signed by the President into law on 7 February 2014. This study provides preliminary analysis of commodity program options for Arkansas crop producers. Hypothetical farm examples based on representative panel farms[1] are evaluated with regard to program decisions that Arkansas producers will make to enroll in the safety net program of the 2014 farm bill. Analysis relies on a stochastic framework since the commodity program options offer a safety net only when prices or revenues fall below fixed reference prices or moving averages of benchmark revenue per acre. Results show that by choosing the Price Loss Coverage (PLC) and the county level Agricultural Risk Coverage (ARC-County) on a crop-by-crop basis, farms are much better-off both in terms of probabilities of receiving payments and amounts of probable payments compared to relying solely on one program for all crops or the alternative ARC-Individual program which is whole-farm based. Results also show the potential benefits from program base acre reallocation and updating of program payment yields.

INTRODUCTION

The 2014 Farm Bill, otherwise known as the Agricultural Act of 2014, was passed on a bipartisan basis by the U.S. House of Representatives on 28 January 2014 and

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[1] Agricultural economists from the Agricultural and Food Policy Center at Texas A&M in concert with agricultural economists from the University of Arkansas System Division of Agriculture maintain and update representative panel farms for Arkansas.

by the U.S. Senate on 4 February 2014; and was signed by the President into law on 7 February 2014. The bill covers the five-year period 2014 to 2018, and includes 12 titles. Title I Commodities, includes the price and revenue support programs: Price Loss Coverage (PLC) and Agricultural Risk Coverage (ARC). These two programs replace the Direct Payment, Counter-Cyclical Payment (CCP), and Average Crop Revenue Election (ACRE) programs of the 2008 Farm Bill which were repealed under the new law.

The regulatory details needed to implement the new law are not expected to be published until later in 2014, hence there is still a lack of definitive information that can be used by producers and other stakeholders to make program enrollment decisions.[2] This analysis is an initial effort to assess the options open to the producers under Title I, based on the authors' understanding of the text of the legislation.[3] Certainly, there will be changes, updates, and modifications as final rules become available.

In this study, we use two representative panel farms in Arkansas which are located in Stuttgart and McGehee to illustrate the probabilities of receiving commodity program payments and to quantify such probable payments under the new law. Unlike previous legislations where direct payments were fixed and certain, the new safety net is probabilistic in the sense that if market prices exceed the bill's reference prices or actual crop or farm revenues are greater than a guaranteed benchmark level, there will be no government payments. Therefore to conduct the analysis, we rely on projected prices and yields for the 2014 to 2018 marketing crop years. We used the preliminary average national farm prices generated by FAPRI-Missouri[4] as of January 2014, with collaborative modeling input from the Arkansas Global Rice Model.[5] These prices are generally higher for corn, wheat, and soybeans; and lower for rice, than the USDA 10-year outlook prices as of February 2014.

Background of Title I under the Agricultural Act of 2014

A summary of the main features of Title I can be found in the policy brief 'Commodity Program Options in the 2014 Farm Bill' prepared by Wailes et al. (2014). The primary source of the information to estimate the results of this study are drawn from the bill Conference Report of the 113th Congress (2014).

Consistent with the provisions of the Food, Conservation and Energy Act of 2008, the three repealed and replaced programs continue to apply through the 2013 crop year

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[2] The USDA is funding the availability of online decision aids to help farmers analyze program options that best suit their particular farming operations. Educational meetings should be attended and the decision aids should be used when they become available. However, there are many choices that producers will need to understand and decide best for their own operations.

[3] The text of the Agricultural Act of 2014 can be found online at: http://beta.congress.gov/113/bills/hr2642/BILLS-113hr2642enr.pdf

[4] The Food and Agricultural Policy Research Institute (FAPRI-Missouri) lead a consortium of universities including the University of Arkansas to generate baseline projections of prices, production, use and trade. Their March 2014 baseline is at: http://www.fapri.missouri.edu/outreach/publications/2014/FAPRI_MU_Report_02_14.pdf

[5] The Arkansas Global Rice Model (AGRM) is developed and maintained by the University of Arkansas System Global Rice Economics Program (AGREP) with the Department of Agricultural Economics and Agribusiness, Division of Agriculture at the University of Arkansas, Fayetteville.

with respect to all covered commodities on a farm, except cotton. For the 2014 through 2018 crop years, all of the producers on a farm shall make a one-time, irrevocable election to enroll in either: (1) PLC or ARC-County on a covered commodity-by-covered-commodity basis; or (2) ARC-Individual.

Farm owners are also given a one-time election of (1) retaining current covered commodity base acres, including any generic base acres (previously cotton program base acres); or (2) reallocation of base acres, other than generic base acres, for covered commodities as in effect on 30 September 2013. If the latter option is selected, reallocation is based on the average ratio of those covered commodities planted to total planted acres on the farm during the 2009 to 2012 crop years, including years with zero planted acres. Cotton base acres are converted to fixed generic acres which can be re-assigned to covered commodities by cropping season based on crop planted ratio.

Program payments are based on base acres, not planted acres. The payment limit per person actively engaged is $125,000 and adjusted gross income (AGI) limit is $900,000 per person or legal entity. No payment will be given if sum of base acres on the farm is less than 10 acres, except for socially disadvantaged or limited resource producers.

PROCEDURES

The new 2014 Farm Bill is relatively more complex than the previous farm bills. The analysis presented in this paper is for two Arkansas representative panel farms. We analyze the relative benefits of the PLC and ARC programs using a stochastic framework generated from multivariate empirical distributions (MVE) derived from historical county yields, farm yields, and national average price variables. The two representative farms are a Stuttgart farm in Arkansas County and a McGehee farm in Desha County. The 2014-2018 FAPRI-Missouri preliminary annual average national commodity price projections of January 2014 are used in the analysis. The 2012 and 2013 farm yields of the two representative farms are provided by Texas A&M Agricultural Food Policy Center (AFPC).[6]

Average deterministic projections on county and farm yields for 2014 to 2018 are generated using trend estimates, given 11 years of County data and 14 years of farm data. To generate stochastic distributions of the national prices, county yields, and farm yields for the 2014 to 2018 period, empirical distributions of historical data are estimated using the Simulation & Econometrics to Analyze Risk (Simetar, College Station, Texas) developed by Richardson et al. (2008). This is similar to the procedure used by Chavez and Wailes in their study on U.S. rice policy (2011). For each program year, 500 sets of projections for the 2014 to 2018 national prices, farm yields, and county yields are estimated, generating 500 sets of payment results for each year with probabilities and amounts of probable payments by program, by farm, and by commodity.

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[6] Double-cropped soybean and corn yields were not available for the Stuttgart farm so we used the yield history of the McGehee farm.

Price Loss Coverage (PLC) and Agricultural Risk Coverage (ARC) Payments

Calculation of the Price Loss Coverage (PLC) Payments

Price Loss Coverage (PLC) Payment is received if the *effective price* for the covered commodity for the crop year is less than the *reference price* for the covered commodity for the crop year. See Table 1 for a list of the reference prices.

Payment Rate = Reference Price – *higher of* (Market Year Average Price or Loan Rate)

PLC Payment = Payment Rate × Payment Yield (*CCP yield under Farm Bill 2008 or updated*) × 0.85 × Base Acres (*current or re-allocated; with generic base re-assignment*), if Payment Rate >0; else 0

A producer can make a *one-time update* of the payment yield for a crop to 90% of the 5 year (2008 to 2012) planted acres average, excluding years in which the planted acreage was zero. For any of the 5 years 2008 to 2012, a minimum plug-in of 75% of the average county yield can replace the yield on the farm if it is lower than this value before computing for the average.

Calculation of the Agricultural Risk Coverage (ARC) Payments

Agricultural Risk Coverage (ARC) Payment is received if the *actual crop revenue* for the crop year is less than the *agriculture risk coverage guarantee* determined for the crop year. Separate calculations are made for irrigated and non-irrigated commodities.

Actual Crop Revenue, County = Actual Average County Yield × *higher of* (Market Year Average Price or Loan Rate)

Actual Crop Revenue, Individual = *sum* [Total Production *of each covered commodity* × *higher* of (Market Year Average Price or Loan Rate)] / Total Planted Acres *of all covered commodities*

Benchmark Revenue, County = Olympic Average County Yield *for the most recent 5 crop years (cannot be lower than 70% of transitional yield*) × Olympic Market Year Average Price *for the most recent 5 crop years (cannot be lower than the reference price)*

Benchmark Revenue, Individual = *for each covered commodity for each of the most recent 5 crop years*, Yield per planted acre (cannot be lower than 70% of transitional yield) × Market Year Average Price (cannot be lower than the reference price) = *for each covered commodity*, Olympic Average of the Revenues determined above for the most recent 5 crop years = *for each of 2014 to 2018 crop years*, Sum of the Amounts determined above for all covered commodities, but adjusted to reflect share ratio of each covered crop to total planted acres

Agricultural Risk Coverage Guarantee, County or Individual = 0.86 × *Benchmark Revenue*

Payment Rate, County or Individual = *lower of* [(Agriculture Risk Coverage Guarantee – Actual Crop Revenue) **or** (0.10 × Benchmark Revenue)]

ARC Payment, County = Payment Rate × 0.85 × Base Acres (*current or re-allocated; with generic base re-assignment*), if Payment Rate > 0; else 0

ARC Payment, Individual = Payment Rate × 0.65 × Base Acres (*current or re-allocated; with generic base re-assignment*), if Payment Rate >0; else 0

Two scenarios are presented for each farm, one assuming no reallocation of base acres and the other with reallocation.

The results include annual percent probabilities of each crop or farm receiving annual payments greater than zero, average amounts of probable annual payments per base acre, and probable annual total farm payments by program for the period 2014 to 2018. Weighted average percent probabilities and probable payment amounts by crop for the entire 5-year period are also estimated. Reallocation of base acres does not change the total base acres of the farm on record as of 30 September 2013. Thus, reallocation of base acres affects only the amount of total probable payments, not the probable payments per base acre. Furthermore, ARC-Individual program which are paid on total farm base acres are not affected by reallocation of base acres.

RESULTS AND DISCUSSION

It should be borne in mind that the results of this analysis can potentially change dramatically from farm to farm and with changes in assumed projected commodity prices, number of base acres, and updated payment yields. Thus for the most part, the set of results generated from the Arkansas Rep Farm Model presented here is dependent on the specific assumptions used in the analysis, as well as our current understanding of the law.

The details of planted acres, base acres, and computed re-assigned generic base and reallocated base acres of the two representative farms are presented in Tables 2a-2c. As of 30 September 2013, the Stuttgart farm operates 3,564 planted acres and grows five crops, including long grain rice, irrigated soybeans, wheat, double-crop soybeans, and corn. The McGehee farm, on the other hand, has 6,325 acres planted to long-grain rice, full-season soybeans, double-crop soybeans, corn, wheat, and irrigated cotton. Cotton is not a covered commodity under the 2014 Farm Bill, i.e., not part of the PLC or the ARC programs hence not included in modeling the farm program payments in the Arkansas Rep Farm Model. However, the law has provided for a transition assistance amount for cotton producers, which is computed as detailed in Appendix 1.

Table 2a shows how base acres are reallocated in the Stuttgart farm. The farm has no generic base acres (formerly called cotton base) to re-assign to covered commodities hence column (e) is zero. The ratios in column (d) are computed from all covered commodities in column (a); the total farm base in column (c) which is equal to 3,475 is multiplied repeatedly by each row in column (d) one row at a time to get column (f); column (f) is added to column (e) which in this case is zero to get the updated base acres in column (g) which now becomes the basis of program payments. Note that consistent with the provision of the law, the total of column (g) does not exceed the total farm base acres in column (c).

Table 2b illustrates how generic base acres (formerly called cotton base) are re-assigned to covered commodities planted in the McGehee farm. First, compute the totals of covered commodities in columns (a) and (b), i.e., exclude acreage for irrigated cotton which is not a covered commodity. The ratios in column (d) are computed from covered commodities in column (b); the irrigated cotton base in column (c) which is 2,058 is multiplied repeatedly by each row in column (d) one row at a time to get column (e); note that the total of column (e) remains equal to 2,058; column (e) is added to column (c) excluding the irrigated cotton base acre to get the updated base acres in column (g) which now becomes the basis of program payments. Again, consistent with the provision of the law, the total of column (g) does not exceed the total farm base acres in column (c). At this stage, it is assumed that there is no reallocation of base acres yet. To simplify the computation, column (b) in this example is assumed to be fixed for the entire 5-year life of the bill (2014 to 2018) but in reality the producer can, and most likely will, change his cropping mix every year.

Reallocation of base acres in the McGehee farm, in addition to re-assignment of generic base acres, is shown in Table 2c. Similar to Table 2a, the ratios in column (d) are computed from column (a) but excluding acres of irrigated cotton which is not a covered commodity; the base acres for the two covered commodities long grain rice (2,058) and full-season (FS) irrigated soybeans (2,241) in column (c) are added to get a total of 4,299 which is then multiplied repeatedly by each row in column (d) one row at a time to get column (f); column (f) is added to column (e) which is computed in Table 2b to get the updated base acres in column (g) which now becomes the basis of program payments. Again, note that consistent with the provision of the law, the total of column (g) does not exceed the total farm base acres in column (c).

The initial results of the Arkansas Rep Farm Model show that the percent probabilities of the farms receiving program payments under the new law and the amount of the probable payments can vary widely by program and by crop. A summary of the weighted average probabilities of receiving payments, the amounts of average probable payments per base acre, and the total probable payments by crop for the entire 5-year program period are estimated and presented in Tables 3a, 3b, 4a, and 4b. Note that the source of differences in ‘crop total’ values between Tables 3a and 3b, and between 4a and 4b lies in the line labeled ‘base acres’ and ‘updated base acres’ in the table. The ‘per base acre’ values and the ARC-Individual totals are the same.

Table 3a shows the results for the Stuttgart farm with retention of base acres (without reallocation) and Table 3b shows the scenario with reallocation of base acres. Tables 4a and 4b show results for the same pair of scenarios, respectively, for the McGehee farm. As discussed earlier, the PLC and the ARC-County can be combined because both programs are implemented on a covered commodity-by-covered-commodity basis in the farm. Following this provision, it is assessed that combining the highlighted columns under PLC and ARC-County in the table is the best option for the farm.

In Table 3a, the Stuttgart farm without reallocation of base acres is better off with a combination of PLC for long-grain rice and wheat, and ARC-County for irrigated soybeans and double crop soybeans. The sum of the probable payments for this combination is $134,085 with a weighted probability of 72% (see the row labeled ‘Selected PLC and ARC-County’). This combination is much superior to the ARC-Individual which has a probable payment of $12,328 with a very low probability of 16%.

With base acre reallocation (Table 3b), the best combination for Stuttgart farm is PLC for long-grain rice and wheat, and ARC-County for irrigated soybeans with a total probable payment of $141,588 and a weighted probability of 73%—again, compared to ARC-Individual's $12,328 and 16% probability.

Without base acre reallocation (Table 4a), the best combination for the McGehee farm is PLC for long-grain rice, wheat, and corn, and ARC-County for both soybeans with combined probable payments of $201,649 at 66% probability. With base acre reallocation, the McGehee farm is better off with the same combination which gives a total probable payment of $171,781 at 59% probability compared to $58,897 and 26% probability for ARC-Individual.

Figures 1 through 4 are graphical representations of Tables 3a, 3b, 4a, and 4b which are provided for quick visual comparison between PLC and ARC-County. The details of the average annual probabilities of receiving annual payments and average annual amounts of the probable payments per base acre by program and by crop by year for the period 2014 to 2018 are presented in Tables 5a and 5b.

Figures 5 and 6 provide a comprehensive comparison of the alternative options for each farm. Each chart shows the weighted percent probabilities and the total farm payments in $1,000 by program or program combination and by base acre decision choice. Figure 5 shows that for Stuttgart, the weighted average probable payment with base acre reallocation is 6% higher than that with base acre retention, although both probabilities are practically the same; and it also shows that the combined probable payments from selected PLC plus ARC-County is vastly superior to those from ARC-Individual program, i.e., by a factor of 11.

A different result is depicted for the McGehee farm in Figure 6 which shows that the weighted average probable payment with base acre reallocation is 15% lower, and the probability is 7 percentage points lower, than that with retention of base acres. Consistent with the results from the Stuttgart analysis, the combined probable payments from selected PLC plus ARC-County in McGehee are substantially superior to those from ARC-Individual program, i.e., by a factor of 3.

Tables 3a and 4a show that in the case of long grain-rice, the PLC program is better than ARC-County in generating both percent probabilities of receiving payments and probable amounts of program payments per base acre. For long-grain rice, both Stuttgart and McGehee representative farms have the same 78% probability of receiving program payments, averaging $66 and $65 per base acre, respectively. Under the ARC-County program, both farms have very low probabilities of receiving program payments for rice (14% to 13%, respectively) with average probable payment amounts of $6 and $5 per base acre, respectively.

For the Stuttgart farm, PLC and ARC-County programs have comparable pair of probabilities of receiving payments and probable payment amounts for wheat. For wheat, PLC has 65% probability of receiving an average of $20 per base acre payment and ARC-County has 52% probability of receiving an average of $14 per base acre payment. There are no values for corn because the Stuttgart farm has no base acre for corn. Irrigated soybeans and double-crop soybeans are relatively better off with ARC-County than PLC, although both have relatively lower probabilities of receiving payments.

Similar to the Stuttgart farm, the full-season and double-crop soybeans in the McGehee farm have relatively higher probabilities of receiving payments and higher probable payment amounts under ARC-County than under PLC. Likewise, the probabilities of receiving payments are relatively low. Corn, however, is better off with PLC than ARC-County for the McGehee farm. PLC wheat has a 65% probability of receiving an average of $22 per base acre payment and ARC-County wheat has only a 19% probability of receiving an average of $3 per base acre payment. For corn, PLC and ARC-County programs have comparable pair of probabilities of receiving payments and probable amounts of payment.

Both farms have relatively low probabilities of receiving payments and low amounts of probable payments under the ARC-Individual program. For the Stuttgart farm, ARC-Farm has a 16% average probability of receiving $4 per base acre payment. For the McGehee farm, the same program has a 26% probability of receiving a payment of $9 per base acre.

The total payments for the entire farm shown at the lower portion of Tables 3 and 4 are obtained by simply multiplying the payment per base acre by the total number of base acres by crop. This highlights the superiority of PLC for long grain rice, with total probable payments of $107, 242 for the Stuttgart farm and $141,121 for the McGehee farm, both with 78% probability of receiving probable payments.

For the Stuttgart farm, irrigated soybean under ARC-County has probable total payments of $18,146 but the probability of receiving payments is only 44%. Long-grain rice under ARC-County has a probable average total payment of $10,262 but a low probability of 14% of receiving that payment. The ARC-Individual has probable total payments of $12,328 with a low probability of 16%. Again, corn has no total payments because the Stuttgart farm has no corn base acre.

In McGehee farm, irrigated soybeans under ARC-County has probable total payments of $36,524 with 35% probability of receiving payments. ARC-Individual has a probable total average payment of $58,897, but the probability of receiving that payment is only 26%. ARC-County, on the other hand, has a probable total payment of $10,376 but with a lower probability (13%) of receiving that payment.

While the results of this study cannot be generalized for other farms, they can serve as a useful guide for producers on how to proceed with the decision-making process related to the new farm bill, given unique characteristics of their own farms.

CONCLUSIONS

The results of this study show that in the case of Stuttgart and McGehee representative farms in Arkansas, the Price Loss Coverage (PLC) program is the best choice for rice and wheat producers in terms of probabilities of receiving payments and the amount of probable payments. Soybean producers are better off with ARC-County. For corn, probable payments from PLC and ARC-County are comparable. In both farms, PLC provides the highest probabilities of receiving payments (78%) and the highest amount of probable program payments ($65-$66 per base acre) for rice. PLC also provides relatively reasonable probability of receiving payments (65%) and amounts of probable payments ($20 to $22 per base acre) for wheat for both farms. For soybeans, ARC-County appears better than PLC for both farms.

Reallocation of base acres can have different results from farm to farm. Results from the two representative farms show that with reallocation the Stuttgart farm is slightly better off, but McGehee farm is relatively worse off. What is clear from both farms is that in terms of probabilities of getting payments and amounts of probable payments, the combined/selected PLC plus ARC-County which are commodity-based are much superior to those from the ARC-Individual program which is farm-based.

This analysis provides preliminary estimates of the impact of the new legislation for Arkansas farms which are needed particularly during the first year of the new Farm Bill.

SIGNIFICANCE OF FINDINGS

This study analyzes the impact of the new Farm Bill 2014 (Agricultural Act of 2014) using representative farms. As the law is new, there is a relative scarcity of analytical information for the producers. This study is an initial attempt to provide a better understanding of the effects of the new law at the farm level. It provides empirical estimates of the probabilities of receiving payments and the probable amounts of payments by program and by crop. It also provides indications of the relative impact of base acre reallocation. These issues are undoubtedly the immediate concerns of the producers and other agricultural stakeholders in Arkansas and elsewhere in the U.S.

More specifically, Arkansas is the major rice-producing state in the U.S and it is quite important for Arkansas rice producers and other stakeholders to have a better understanding of the relevant features of the new U.S. agricultural policy embodied under the new law. This new policy has the potential to have an important impact not only on the state's crop economy but the global market as well.

ACKNOWLEDGMENTS

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Table 1. Reference prices under Farm Bill 2014.

Long-grain rice, cwt[a]	$14.00
Medium-grain rice, cwt	$14.00
Japonicas, cwt	$16.10
Wheat, bu	$5.50
Corn, bu	$3.70
Grain sorghum, bu	$3.95
Barley, bu	$4.95
Oats, bu	$2.40
Soybeans, bu	$8.40
Other oilseeds, cwt	$20.15
Dry peas, cwt	$11.00
Lentils, cwt	$19.97
Small chickpeas, cwt	$19.04
Large chickpeas, cwt	$21.54
Peanuts, ton	$535.00

[a] Cwt = hundredweight, bu = bushel.

Table 2a. Updated base acres with base reallocation, Stuttgart Representative Farm.

Crops[a]	(a) Assumed 2009-2012 planted acres	(b) Assumed 2014-2018 planted acres	(c) 30 Sept. 2013 base acres[b]	(d) 2009-2012 crop ratio	(e) Re-assigned generic base[c]	(f) Re-allocated base acres	(g) Updated
Long-grain rice	1,620	1,296	1,620	0.50	0	1,738	1,738
Irrig. soybeans	1,296	1,296	1,296	0.40	0	1,390	1,390
Wheat	324	324	235	0.10	0	348	348
DC soybeans	0	324	324	0.00	0	0	0
Corn	0	324	0	0.00	0	0	0
Total	3,240	3,564	3,475	1.00	0	3,475	3,475

Table 2b. Updated base acres with reassignment of generic base, before base reallocation, McGehee Representative Farm.

Crops[a]	(a) Assumed 2009-2012 planted acres	(b) Assumed 2014-2018 planted acres	(c) 30 Sept. 2013 base acres[b]	(d) 2009-2012 crop ratio	(e) Re-assigned generic base[c]	(f) Re-allocated base acres	(g) Updated
Long-grain rice	1,875	325	2,058	0.05	106	0	2,164
FS irrig. soybeans	1,625	2,600	2,241	0.41	846	0	3,087
DC soybeans	750	150	0	0.02	49	0	49
Corn	1,500	3,100	0	0.49	1,009	0	1,009
Wheat	1,000	150	0	0.02	49	0	49
Irrigated cotton	1,500	325	2,058				
Total	6,750	6,325	6,357	1.00	2,058	0	6,357

Table 2c. Updated base acres with reassignment of generic base acres and base reallocation, McGehee Representative Farm.

Crops[a]	(a) Assumed 2009-2012 planted acres	(b) Assumed 2014-2018 planted acres	(c) 30 Sept. 2013 base acres[b]	(d) 2009-2012 crop ratio	(e) Re-assigned generic base[c]	(f) Re-allocated base acres	(g) Updated
Long-grain rice	1,875	325	2,058	0.28	106	1,194	1,300
FS irrig. soybeans	1,625	2,600	2,241	0.24	846	1,035	1,881
DC soybeans	750	150	0	0.11	49	478	526
Corn	1,500	3,100	0	0.22	1,009	955	1,964
Wheat	1,000	150	0	0.15	49	637	686
Irrigated cotton	1,500	325	2,058				
Total	6,750	6,325	6,357	1.00	2,058	4,299	6,357

[a] DC = double cropped, FS = full season.

[b] The two covered commodities (long-grain rice and FS irrig. soybeans) are reallocated (total of 4,299 acres).

[c] Computed in the previous table.

Table 3a. Stuttgart farm without base acre reallocation: five-year weighted probabilities of receiving payments and probable annual payments per base acre and for the entire farm using Food and Agricultural Policy Research Institute January 2014 projected prices by program and by crop, 2014-2018.

	Stuttgart									
Program/crop	Long-grain rice		Irrigated soybeans		Wheat		Double-cropped soybeans		Corn	
Base acres	1620		1296		235		324		0	
Per base acre	Probability	Payment	Probability	Payment	Probability	Payment	Probability	Payment	Probability	Payment
	(%)	($)	(%)	($)	(%)	($)	(%)	($)	(%)	($)
PLC[a]	78	66	12	2	65	20	12	2	0	0
ARC-County	14	6	44	14	52	14	35	12	0	0
	All Farm									
ARC-Individual (Farm)	16	4								
Crop total	Probability	Payment	Probability	Payment	Probability	Payment	Probability	Payment	Probability	Payment
	(%)	($)	(%)	($)	(%)	($)	(%)	($)	(%)	($)
PLC	78	107,242	12	2,469	65	4,805	12	601	0	0
ARC-County	14	10,262	44	18,146	52	3,302	35	3,891	0	0
Selected PLC and ARC-County	72	134,085								
	All Farm									
ARC-Individual (Farm)	16	12,328								

[a] PLC = price loss coverage, ARC = agricultural risk coverage.

Note: The PLC and ARC-County can be combined because both programs are implemented on a covered commodity-by-covered-commodity basis in the farm. Following this provision, it is assessed that combining the highlighted columns under PLC and ARC-County in the table above is the best option for this farm.

Table 3b. Stuttgart farm with base acre reallocation: five-year weighted probabilities of receiving payments and probable annual payments per base acre and for the entire farm using Food and Agricultural Policy Research Institute January 2014 projected prices by program and by crop, 2014-2018.

	Stuttgart									
Program/crop	Long-grain rice		Irrigated soybeans		Wheat		Double-cropped soybeans		Corn	
Base acres	1738		1390		348		0		0	
Per base acre	Probability	Payment	Probability	Payment	Probability	Payment	Probability	Payment	Probability	Payment
	(%)	($)	(%)	($)	(%)	($)	(%)	($)	(%)	($)
PLC[a]	78	66	12	2	65	20	0	0	0	0
ARC-County	14	6	44	14	52	14	0	0	0	0
	All Farm									
ARC-Individual (Farm)	16	4								
Crop total	Probability	Payment	Probability	Payment	Probability	Payment	Probability	Payment	Probability	Payment
	(%)	($)	(%)	($)	(%)	($)	(%)	($)	(%)	($)
PLC	78	115,021	12	2,648	65	7,105	0	0	0	0
ARC-County	14	11,007	44	19,462	52	4,883	0	0	0	0
Selected PLC and ARC-County	72	141,588								
	All Farm									
ARC-Individual (Farm)	16	12,328								

[a] PLC = price loss coverage, ARC = agricultural risk coverage.

Note: The PLC and ARC-County can be combined because both programs are implemented on a covered commodity-by-covered-commodity basis in the farm. Following this provision, it is assessed that combining the highlighted columns under PLC and ARC-County in the table above is the best option for this farm.

Table 4a. McGehee farm without base acre reallocation[a]: five-year weighted probabilities of receiving payments and probable annual payments per base acre and for the entire farm using Food and Agricultural Policy Research Institute January 2014 projected prices by program and by crop, 2014-2018.

	McGehee									
Program/crop	Long-grain rice		Irrigated soybeans		Wheat		Double-cropped soybeans		Corn	
Base acres	2164		3087		49		49		1009	
Per base acre	Probability	Payment	Probability	Payment	Probability	Payment	Probability	Payment	Probability	Payment
	(%)	($)	(%)	($)	(%)	($)	(%)	($)	(%)	($)
PLC[b]	78	65	12	2	65	22	12	2	36	22
ARC-County	13	5	35	12	19	3	35	12	34	20
	All Farm									
ARC-Individual (Farm)	26	9								
Crop total	Probability	Payment	Probability	Payment	Probability	Payment	Probability	Payment	Probability	Payment
	(%)	($)	(%)	($)	(%)	($)	(%)	($)	(%)	($)
PLC	78	141,121	12	6,331	65	1,060	12	91	36	22,358
ARC-County	13	10,376	35	36,524	19	124	35	586	34	20,037
Selected PLC and ARC-County	66	201,649								
	All Farm									
ARC-Individual (Farm)	26	58,897								

[a] With generic base acre re-assignment to covered commodities.

[b] PLC = price loss coverage, ARC = agricultural risk coverage.

Note: The PLC and ARC-County can be combined because both programs are implemented on a covered commodity-by-covered-commodity basis in the farm. Following this provision, it is assessed that combining the highlighted columns under PLC and ARC-County in the table above is the best option for this farm.

Table 4b. McGehee farm with base acre reallocation[a]: five-year weighted probabilities of receiving payments and probable annual payments per base acre and for the entire farm using Food and Agricultural Policy Research Institute January 2014 projected prices by program and by crop, 2014-2018.

	McGehee									
Program/crop	Long-grain rice		Irrigated soybeans		Wheat		Double-cropped soybeans		Corn	
Base acres	1300		1881		686		526		1964	
Per base acre	Probability	Payment	Probability	Payment	Probability	Payment	Probability	Payment	Probability	Payment
	(%)	($)	(%)	($)	(%)	($)	(%)	($)	(%)	($)
PLC[b]	78	65	12	2	65	22	12	2	36	22
ARC-County	13	5	35	12	19	3	35	12	34	20
	All Farm									
ARC-Individual (Farm)	26	9								
Crop total	Probability	Payment	Probability	Payment	Probability	Payment	Probability	Payment	Probability	Payment
	(%)	($)	(%)	($)	(%)	($)	(%)	($)	(%)	($)
PLC	78	84,781	12	3,857	65	14,890	12	977	36	43,533
ARC-County	13	6,233	35	22,254	19	1,745	35	6,323	34	39,015
Selected PLC and ARC-County	59	171,781								
	All Farm									
ARC-Individual (Farm)	26	58,897								

[a] With generic base acre re-assignment to covered commodities.

[b] PLC = price loss coverage, ARC = agricultural risk coverage.

Note: The PLC and ARC-County can be combined because both programs are implemented on a covered commodity-by-covered-commodity basis in the farm. Following this provision, it is assessed that combining the highlighted columns under PLC and ARC-County in the table above is the best option for this farm.

Table 5a. Annual stochastic probabilities and average representative farm using Food and Agricultural Policy Research Institute's

	Long-grain rice					Irrigated soybeans				
PLC[a]	2014	2015	2016	2017	2018	2014	2015	2016	2017	2018
No. of draws > 0 payment	279	420	418	422	423	57	67	65	61	56
% of draws > 0 payment	56%	84%	84%	84%	85%	11%	13%	13%	12%	11%
Average payments, $/base acre										
For all 500 draws	$27	$76	$73	$77	$78	$2	$2	$2	$2	$2
5-Year average payment per base acre (500 draws/yr)					$66					$2
5-Year weighted % probability of payment > 0					78%					12%

	Long-grain rice					Irrigated soybeans				
ARC-County	2014	2015	2016	2017	2018	2014	2015	2016	2017	2018
No. of draws > 0 payment	6	77	84	99	92	331	368	336	72	0
% of draws > 0 payment	1%	15%	17%	20%	18%	66%	74%	67%	14%	0%
Average payments, $/base acre										
For all 500 draws	$0	$6	$8	$9	$8	$24	$26	$19	$1	$0
5-Year average payment per base acre (500 draws/yr)					$6					$14
5-Year weighted % probability of payment > 0					14%					44%

	All farm				
ARC-Individual	2014	2015	2016	2017	2018
No. of draws > 0 payment	67	152	115	56	9
% of draws > 0 payment	13%	30%	23%	11%	2%
Average payments, $/base acre					
For all 500 draws	$3	$7	$5	$2	$0
5-Year average payment per base acre (500 draws/yr)					$4
5-Year weighted % probability of payment > 0					16%

[a] PLC = price loss coverage, ARC = agricultural risk coverage.

probable program payments per acre for Stuttgart
preliminary January 2014 projected prices by crop, 2014-2018.

Wheat					Double crop soybeans					Corn				
2014	2015	2016	2017	2018	2014	2015	2016	2017	2018	2014	2015	2016	2017	2018
294	332	334	331	331	57	67	65	61	56	0	0	0	0	0
59%	66%	67%	66%	66%	11%	13%	13%	12%	11%	0%	0%	0%	0%	0%
$16	$22	$22	$21	$21	$2	$2	$2	$2	$2	$0	$0	$0	$0	$0
				$20					$2					$0
				65%					12%					0%

Wheat					Double crop soybeans					Corn				
2014	2015	2016	2017	2018	2014	2015	2016	2017	2018	2014	2015	2016	2017	2018
338	395	391	90	82	302	333	236	6	0	0	0	0	0	0
68%	79%	78%	18%	16%	60%	67%	47%	1%	0%	0%	0%	0%	0%	0%
$21	$24	$21	$2	$2	$23	$25	$12	$0	$0	$0	$0	$0	$0	$0
				$14					$12					$0
				52%					35%					0%

Table 5b. Annual stochastic probabilities and average representative farm using Food and Agricultural Policy Research Institute's

	Long-grain rice					Full season soybeans				
PLC[a]	2014	2015	2016	2017	2018	2014	2015	2016	2017	2018
No. of draws > 0 payment	279	420	418	422	423	57	67	65	61	56
% of draws > 0 payment	56%	84%	84%	84%	85%	11%	13%	13%	12%	11%
Average payments, $/base acre										
For all 500 draws	$27	$74	$72	$76	$77	$2	$3	$2	$2	$2
5-Year average payment per base acre (500 draws/yr)					$65					$2
5-Year weighted % probability of payment > 0					78%					12%

	Long-grain rice					Full season soybeans				
ARC-County	2014	2015	2016	2017	2018	2014	2015	2016	2017	2018
No. of draws > 0 payment	6	73	79	89	81	01	330	233	4	0
% of draws > 0 payment	1%	15%	16%	18%	16%	60%	66%	47%	1%	0%
Average payments, $/base acre										
For all 500 draws	$0	$5	$6	$7	$6	$22	$25	$12	$0	$0
5-Year average payment per base acre (500 draws/yr)					$5					$12
5-Year weighted % probability of payment > 0					13%					35%

	All farm				
ARC-Individual	2014	2015	2016	2017	2018
No. of draws > 0 payment	213	212	156	63	0
% of draws > 0 payment	43%	42%	31%	13%	0%
Average payments, $/base acre					
For all 500 draws	$17	$17	$10	$2	$0
5-Year average payment per base acre (500 draws/yr)					$9
5-Year weighted % probability of payment > 0					26%

[a] PLC = price loss coverage, ARC = agricultural risk coverage.

probable program payments per acre for McGehee
preliminary January 2014 projected prices by crop, 2014-2018.

Wheat					Double crop soybeans					Corn				
2014	2015	2016	2017	2018	2014	2015	2016	2017	2018	2014	2015	2016	2017	2018
294	332	334	331	331	57	67	65	61	56	177	179	177	179	179
59%	66%	67%	66%	66%	11%	13%	13%	12%	11%	35%	36%	35%	36%	36%
$17	$23	$23	$23	$23	$2	$2	$2	$2	$2	$22	$22	$22	$22	$22
				$22					$2					$22
				65%					12%					36%

Wheat					Double crop soybeans					Corn				
2014	2015	2016	2017	2018	2014	2015	2016	2017	2018	2014	2015	2016	2017	2018
214	79	65	62	64	302	333	236	6	0	259	281	219	56	46
43%	16%	13%	12%	13%	60%	67%	47%	1%	0%	52%	56%	44%	11%	9%
$8	$2	$1	$1	$1	$23	$25	$12	$0	$0	$34	$38	$24	$2	$1
				$3					$12					$20
				19%					35%					34%

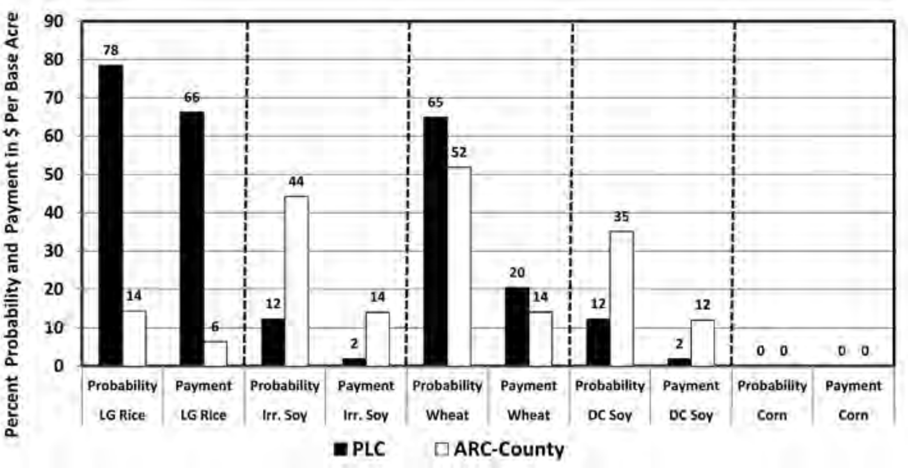

Fig. 1. Probabilities for receiving payments and probable payments per base acre for Stuttgart farm, price loss coverage (PLC) and agricultural risk coverage (ARC)-County, Food and Agricultural Policy Research Institute (FAPRI) Prices.

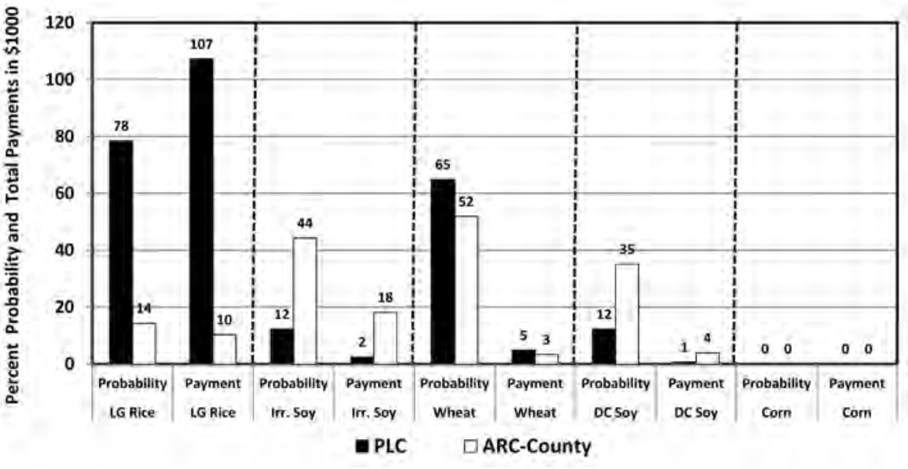

Fig. 2. Probabilities of receiving payments and probable total payments for Stuttgart farm, price loss coverage (PLC) and agricultural risk coverage (ARC)-County, Food and Agricultural Policy Research Institute (FAPRI) Prices.

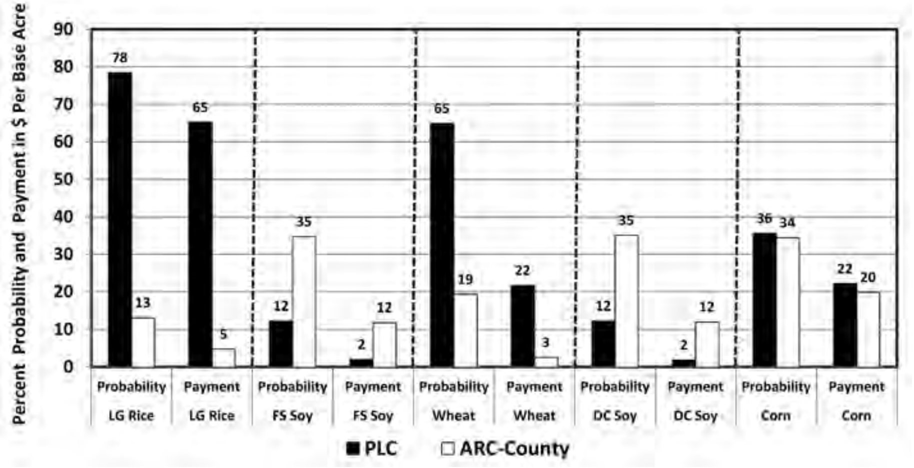

Fig. 3. Probabilities of receiving payments and probable payments per base acre for McGehee farm, price loss coverage (PLC) and agricultural risk coverage (ARC)-County, Food and Agricultural Policy Research Institute (FAPRI) Prices.

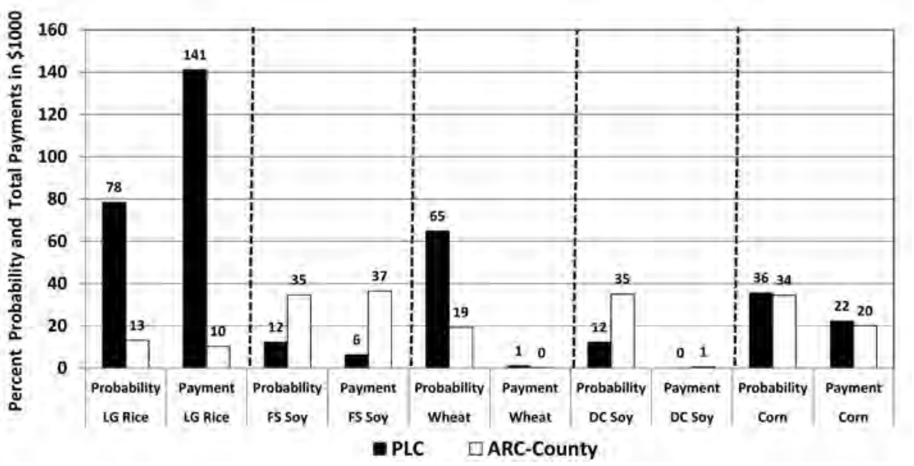

Fig. 4. Probabilities of receiving payments and probable total payments for McGehee farm, price loss coverage (PLC) and agricultural risk coverage (ARC)-County, Food and Agricultural Policy Research Institute (FAPRI) Prices.

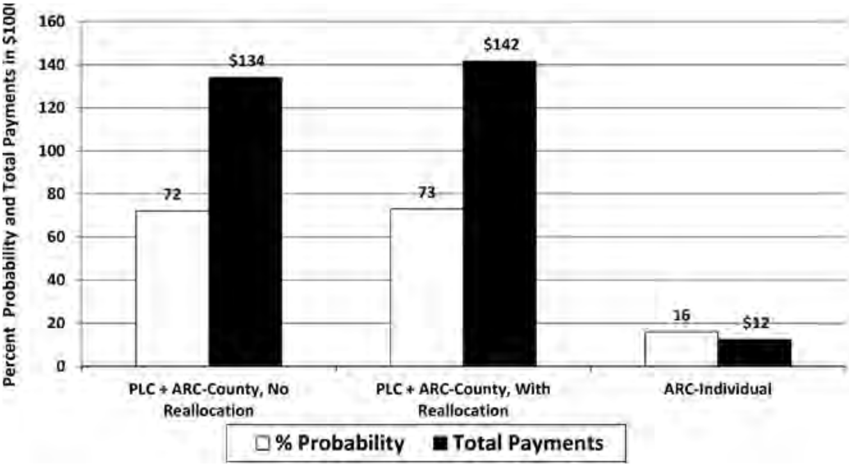

Fig. 5. Stuttgart farm: weighted % probabilities and total farm payments (in $1000), by program and base reallocation choice, Food and Agricultural Policy Research Institute Prices. PLC = price loss coverage and ARC = agricultural risk coverage (ARC)-County.

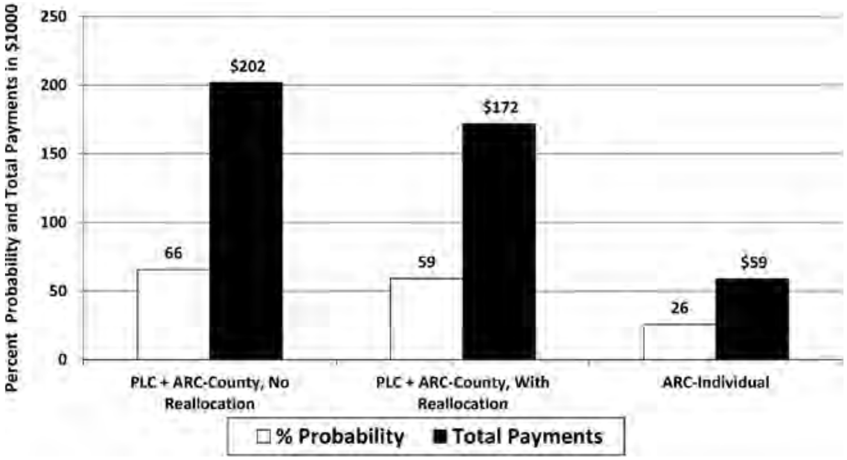

Fig. 6. McGehee farm: weighted % probabilities and total farm payments (in $1000), by program and base reallocation choice, Food and Agricultural Policy Research Institute Prices. PLC = price loss coverage and ARC = agricultural risk coverage (ARC)-County.

Appendix

Transition Assistance for Cotton

Transition assistance will be provided to upland cotton producers if the farm had cotton base acres for the 2013 crop year and is located in a county in which the Stacked Income Protection Plan required by the Federal Crop Insurance Act (7 U.S.C. 1508b) is not available for the 2015 crop year.

The transition assistance rate shall be equal to the product of:

(1) The June 12, 2013, midpoint estimate for the marketing year average price of upland cotton received by producers for the marketing year beginning August 1, 2013, minus the December 10, 2013 midpoint estimate for the marketing year average price of upland cotton received by producers for the marketing year beginning August 1, 2013, as contained in the applicable WASDE report published by USDA (this amounts to 5.4 cents per pound in 2013), AND

(2) The national program yield for upland cotton is 597 pounds per acre.

Calculation of Amount Transition Assistance

The amount of transition assistance shall be equal to the product of:

(1) For the 2014 crop year, 60%, and for the 2015 crop year, 36.5%, of the cotton base acres for the farm, subject to adjustment or reduction for conservation measures;

(2) The transition assistance rate in effect for the crop year; and

(3) The payment yield for upland cotton for the farm under the Food, Conservation, and Energy Act of 2008, divided by the national program yield for upland cotton of 597 pounds per acre.

Trade, Price, and Welfare Impacts of Thailand's Paddy Pledging Program on Global Rice

E.J. Wailes, E.C. Chavez, and A. Durand-Morat

ABSTRACT

Thailand's Paddy Pledging Program (PPP) has created an excessive domestic rice stockpile, causing budgetary and operational controversies in the country and uncertainties in the global rice market. This study looks at the deterministic and stochastic impacts on global rice trade, price, and net welfare of potential release of Thailand's excess rice stocks into the international market. Results show that the potential rice trade supply shock results in lower global rice price and expanded global rice consumption. While rice producers are worse off and rice consumers are better off, the overall net welfare changes are relatively moderate. Relative to partial release, the total release of the country's excess rice stocks can have the potential benefit of lower volatility in global prices. The stochastic analysis generates useful probability distributions of outcomes that indicate risks and uncertainties which are inherent in agricultural enterprises and markets such as rice, and provides a better understanding of the response dynamics of the global rice market.

INTRODUCTION

Trade welfare analysis of a large country typically focuses on how costs of its policies are passed on to the rest of the world. However, in this study we analyse a domestic price policy of Thailand which has caused the country to lose its long-standing dominant position in global rice trade, and analyse its potential consequences on the major players in the international rice market.

Rice is the most important food crop of the developing world and the staple food of more than half of the world's population. In most developing regions, the availability of rice is closely associated with food security and political stability. Shortages of rice and spikes in rice prices have caused social unrest in a number of countries in the past (IRRI, 2013). Thus, shocks to supply and demand of the global rice market have important food security consequences, particularly for import-dependent, food-deficit regions of the world.

In October 2011, following an election promise to improve Thailand farmers' income, Thailand's then newly elected Prime Minister Yingluck Shinawatra implemented a paddy price-floor support policy called the Paddy Pledging Program (PPP). This program guarantees minimum prices for paddy rice—which initially were 30% to 50% higher than world market prices—resulting in a separation between Thailand and other Asian rice exporter prices. Consequently, Thailand's rice export volumes in 2011 declined dramatically, i.e. by 44%, while export supplies from the three other major exporters (India, Vietnam, and Pakistan) dominated international trade.

Despite criticisms and opposition to the PPP, the government of Thailand has continued the program; and has recently re-authorized the extension of the scheme for marketing year 2013/14. So far, the rice purchases of the program have cost US$22 billion, excluding administrative costs, which has exceeded the original US$16 billion authorized by the government (USDA-FAS, 2013). With the country's abnormally high program costs and still mounting rice stocks, storage concerns, and limited export sales of its high-priced rice, coupled with abundant rice supplies elsewhere, it is becoming more likely that Thailand will soon have no choice but to reform this program and subsidize exports of its excess rice stocks on the open international market at prevailing low prices—with a potential shock to global rice supply, demand, and prices.

Policy measures such as Thailand's PPP cause significant distortions in domestic and international markets, the full extent of which has not been adequately assessed. While the goal of raising domestic rice prices has been achieved, the overall impact of the scheme on Thailand's rice supply chain and the global rice market is not clear. The objective of this study is to analyze the potential static and dynamic impacts of the PPP on the global rice market with a focus on production, consumption, trade and prices; and draw conclusions about the redistributive impacts on economic benefits and food security among selected countries.

Thailand's PPP is both empirically interesting and controversial. Large country domestic price support distortions have typically focused on developed agricultural countries. Thailand as a developing country is engaged in a significant impact on the global rice market with impacts on other developing countries. Given that rice is the most important food crop of the developing world usually associated with food security and the rice price crisis in 2007/2008 is still relatively fresh, it is important to analyze the economic consequences of what likely will be a necessary action of stock disposal on the world rice market.

PROCEDURES

In this study, we analyze the short-term and long-term impacts on global rice of Thailand's PPP by assuming an export supply shock as the country releases to the market its excessive rice stockpile. We use the Arkansas Global Rice Model (AGRM)[1], a partial equilibrium, non-spatial, multi-country statistical simulation and econometric analytical framework developed and maintained by the University of Arkansas Global Rice Economics Program (AGREP) with the Department of Agricultural Economics and Agribusiness at the University of Arkansas, Fayetteville. The model is disaggregated into five world regions: Africa, the Americas, Asia, Europe, and Oceania.

The AGRM covers 51 countries/regions[2] that can be used to analyze short-term and long-term impacts of price, supply, and demand scenarios in the global rice market. The historical rice data are drawn from the U.S. Department of Agriculture's Production, Supply, and Distribution (PS&D) database and the macroeconomic data are from IHS Global Insight through the Food and Agricultural Policy Research Institute. Each country and regional model includes a supply and a demand framework, trade, stocks, and price linkage equations. The analysis is done dynamically and stochastically in order to improve assessment of this controversial policy.

The potential impact of Thailand's PPP on global rice and selected countries is evaluated by shocking the release of 'excess stocks'. Over the 3-year period covering 2008-2010, i.e., prior to the implementation of the PPP, Thailand's rice ending stocks-to-use ratio averaged 0.28, with an average of 5.5 million metric tons (mmt) of stocks, 10.0 mmt of domestic consumption, and 9.4 mmt of exports. Stocks accumulated excessively during the implementation of PPP. Two release scenarios (50% and 100% of excess stocks) for Thailand are evaluated for changes in selected variables—area harvested, production, consumption, trade, prices, producer surplus, consumer surplus, and net welfare of Thailand and major rice importers and exporters. In order to present a more comprehensive understanding of the extent of impacts of this controversial policy, the analysis consists of three distinct sections, as follows:

1. A deterministic analysis which presents average annual projected impacts of one-time annual shocks of 50% and 100% releases of excess Thailand rice stocks;
2. A welfare analysis which evaluates the changes in producer surplus, consumer surplus, and net welfare of the shocks described in (a) above; and
3. A stochastic analysis based on uncertainties associated with production, presenting a confidence interval for the two stocks release scenarios.

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[1] The details and the theoretical structure and the general equations of the model are documented online by Wailes and Chavez (2011).

[2] **Africa:** Cameroon, Cote D'Ivoire, Egypt, Ghana, Guinea, Kenya, Liberia, Mali, Mozambique, Nigeria, Senegal, Sierra Leone, South Africa, Tanzania, ECOWAS-7, and Rest-of-Africa; **Americas:** Argentina, Brazil, Canada, Colombia, Mexico, United States, Uruguay, and Rest-of-Americas; **Asia:** Bangladesh, Cambodia, People's Republic of China, China-Hong Kong, India, Indonesia, Iran, Iraq, Japan, Malaysia, Myanmar, Pakistan, the Philippines, Saudi Arabia, South Korea, Taiwan, Thailand, Turkey, Vietnam, Laos, Brunei Darussalam, Singapore, and Rest-of-Asia; **Europe:** EU 27 and Rest-of-EU; and Oceania: Australia and Rest-of-Oceania.

Implementation of the Two Scenarios in the Arkansas Global Rice Model

1. Deterministic Analysis

As defined above, excess stocks are the quantity of Thailand's beginning rice stocks which exceed 28% of total rice use over the projection period. Following the implementation of the PPP, i.e. from 2011-2012, the Thailand's rice stocks almost doubled from 5.5 mmt to 10.9 mmt and exports declined by 26% to just under 7.0 mmt. As the baseline results will show, Thailand's rice stocks are expected to expand further if the government continues to extend the PPP policy.

In the absence of a definite plan to end the PPP, our 10-year model baseline projections from 2013-2022 assume that the program is maintained over the entire period. To reflect the uncertainty, results are evaluated and presented on a yearly basis. With an increasing list of problems associated with maintaining an ever-increasing rice stock level, Thailand eventually has to find a way at some point to release its excessive rice stocks onto the world market. In this paper, excessive rice stock levels for Thailand are defined as stocks beyond the average three-year historical stock-to-use (STU) ratio of 0.28 as mentioned above. This analysis looks at two excess stock release scenarios: 50% and 100% of this excess. These scenarios are based on the assumption that Thailand can peg prices at attractively competitive levels; and that the world market and some new equilibrium price can absorb the country's abnormally high volume of exports. The analysis covers the 10-year period 2013 through 2022.

The impact of each scenario on the world rice market is measured by the resulting differences between the baseline values and the resulting scenario numbers. Discussion in this first section is focused on changes on production, consumption, trade, and prices. In order to generate the initial average deterministic shocks, each scenario is implemented as described below:

a. In the model, the stocks variable is endogenous, with its own equation; and the exports variable is residual.
b. For each year, the 'normal' Thailand rice STU value equivalent to the 0.28, using the baseline consumption plus exports, is computed. These stock levels range from 6.0 to 6.3 mmt.
c. The difference between Thailand's baseline stocks level and the 'normal' computed stocks at 0.28 STU is considered the excess stocks.
d. For the first scenario, 50% of Thailand's excess stocks is assumed exported; and for the second scenario, 100% of Thailand's excess stocks is assumed exported.
e. Each scenario is implemented for each year by manually adjusting the error term in the stocks equation to satisfy the assumed percent release level accordingly.
f. The model is then iterated until world rice market equilibrium is reached, which is defined as the point at which the model's global net rice trade is balanced, i.e., net exports = net imports.
g. The results for each scenario are saved for further consolidation and analysis.

2. *Welfare Analysis*

Welfare analysis is an important component of this study as it contributes to the better understanding of the intricacies of the program and its potential consequences on the global rice economy. Estimates of the consequent welfare distribution among major trading countries due to trade policy interventions imposed by major countries can provide a more in-depth understanding of the effects of those policies (Tun-Hsiang et al., 2011). Considering that changes in trade policies affect both producers and consumers, the welfare analysis for each selected country in this study consists of quantifying the changes in producer surplus (PS) and consumer surplus (CS) using the variables: consumption, production and real prices (in 2000 U.S. dollars) generated from the model simulations. Estimates are computed using the Excel procedure described by Jechlitschka et al. (2007) based on the typical Cobb-Douglas function, given values of rice supply elasticity and rice price elasticity of demand by country generated by AGRM and adopted by Tun-Hsiang et al. (2011).These elasticities by country are as follows:

Country	Supply	Demand
U.S.	0.60	-0.12
China	0.22	-0.10
India	0.09	-0.04
Indonesia	0.10	-0.13
Philippines	0.04	-0.25
Thailand	0.15	-0.05
Vietnam	0.01	-0.20

3. *Stochastic Analysis*

In light of the structural characteristics of the global rice economy, a stochastic analysis is included to develop estimates of the likely upper and lower bounds for selected variables. The stochastic framework is generated using multivariate empirical distributions (MVE) of the yield variable for each of the 51 countries and regions in the model. Yield is used because it is the variable that not only varies by year and by country but it is also very sensitive to changes in weather conditions and water availability—factors that are critical for rice production. The MVE take into account serial and geographical covariance. A total of 100 random draws are implemented using a 28-year empirical distribution of historical yields generated using the software Simulation & Econometrics to Analyze Risk (Simetar) developed by Richardson et al. (2008).

The stochastic analysis generates a range of possible outcomes (confidence intervals), as opposed to the average values generated by deterministic analysis. Stochastic estimates are useful given the fact that underlying assumptions in the average deterministic estimates generally do not hold true in reality, i.e., actual market outcomes usually deviate from average estimates. Stochastic analysis provides information on risk and uncertainty which is an important characteristic of agricultural commodity enterprises and markets, such as that of rice. This section uses a similar method used by Chavez and Wailes (2011) and Wailes and Chavez (2012).

RESULTS AND DISCUSSION

1. Deterministic Analysis

Results show that the major potential impacts of the release of excess Thailand rice stocks in 2013 are on price, consumption, and trade; and lagged response on area harvested and production thereafter (Tables 1a-c and 2a-c). The deterministic analysis shows the average impact of a one-time shock on the model. At 50% Thailand excess stocks release, global rice net trade expands by 11.5% with a consequent decline of 16% in the long-grain international reference price. The impacts nearly double under the 100% excess stocks release scenario, with global rice net trade expanding by 23.1% and an approximate 28% decline in the long-grain rice international reference price. The U.S. long-grain rice export price, on the other hand, declines by 9.4% and 17.4% under the two scenarios, respectively.

Vietnam's rice exports suffer the greatest declines, i.e., at 13.3% and 26.2% under the two scenarios, respectively (Tables 1c and 2c). As global rice trade increases, total world rice consumption expands by 1.3% in 2013 under the 50% scenario and by 2.5% under the 100% scenario—with a combined 60% accounted for by China, Indonesia, Philippines, and Vietnam (Tables 1a and 2a). The decline in rice price could encourage a shift from wheat to rice, as rice and wheat are substitute staples in major countries like China and Indonesia. On average, global rice consumption gains by nearly 1.4 mmt/year under the 50% scenario and 2.8 mmt/year under the 100% scenario over the 10-year period.

The 50% and 100% scenarios cause global rice production in 2014 to decline by 3.8 mmt and 7.1 mmt, respectively—about 74% of which is accounted for by China, Bangladesh, Indonesia, Pakistan, and the U.S. (Tables 1a and 2a). The potential global impact of the release of Thailand's excess rice stocks could partially be neutralized by China's ability to manage its big rice stockpile, i.e. withdraw stocks as needed, in order to mitigate the negative effects of the country's decreased production and expanded consumption.

2. Welfare Analysis

Understanding the welfare implications of the scenarios adds another important dimension to the analysis. Results show that in general, the rice producers are worse off and rice consumers are better off under both stock release scenarios (Tables 3a-c and 4a-c). Rice producers in China are faced with the highest potential loss, followed by Indonesian, Vietnamese, and Philippine rice producers. U.S. and Indian rice producers have relatively lower losses. The producers' losses result from a combination of lower prices and lower production. As the support price under the PPP is maintained, rice producers in Thailand are not expected to incur losses.

Rice consumers, on the other hand, have substantial gains under the scenarios due to lower prices, with the Chinese consumers gaining the most benefit. Rice consumers in Indonesia, Thailand, the Philippines, and Vietnam will also benefit considerably.

Combining the effects on both producers and consumers, the net welfare changes show that only Vietnam has considerable net losses in 2013, and has sustained substantial net annual losses over the 10-year period. The U.S. will also have net losses, albeit to a lesser degree. Losses for China's producers, however, are potentially compensated by the gains for Chinese consumers—resulting in minimal net welfare change. A similar situation is true for India. The Philippines and Indonesia, on the other hand, could potentially earn net benefits from the same scenarios as these are food-deficit and net rice importing countries. Thailand, however, has the largest net welfare, as consumers benefit and producers remain unaffected.

3. Stochastic Analysis

The stochastic analysis provides information on risk and uncertainty which is an important characteristic of agricultural commodity enterprises and markets, such as that of rice. It generates probability distributions of outcomes presented as probability distribution functions (PDFs) which describe both values and likelihoods of outcomes. This is illustrated in Fig. 1 for the two scenarios which show the 2013 outcome PDFs for world total trade, international reference price, and consumption; and 2014 PDF for production. Production is a lagged variable hence 2014 is presented. The PDF divides the frequency distribution into four equal parts—the lower quartile represents the 25th percentile, the second quartile the 50th percentile (or median), and the upper quartile the 75th percentile.

Except in the case of the international price, the shapes of the 2013 PDFs of the other three variables have only minor differences between the two scenarios. Compared to those of the 50% release of excess stocks, the average 2013 international price at 100% stock release is 15% lower; and the price distribution is less dispersed, indicating less volatility. The gap between the start and ending values for the international price is \$218 under the 50% release scenario and \$182 under the 100% release scenario, a difference of \$36 or about 10% of the average price. This indicates a wider price outcome distribution for the 50% release scenario. Under both scenarios, the 2013 price PDFs are skewed to the right (i.e., positively-skewed) indicating asymmetric distribution with larger number of prices toward the left (lower) side. The rest of the individual years could be illustrated the same way, but are not presented here due to space consideration.

Additionally, to show the direction and spread of the stochastic outcome distribution over the entire 10-year period covered in the analysis, three selected outcome items (stochastic average, 10th percentile, and 90th percentile) for selected variables are presented in Figs. 2 and 3 for the two scenarios, respectively. Chavez and Wailes (2011) mentioned that intuitively, the gap between the two percentiles can be taken as a proxy for volatility. Widening indicates increased volatility and narrowing indicates decreased volatility. The spread between the 10th and 90th percentiles under the 100% excess stock release is lower by 1% to 5% than that of the 50% stock release—again indicating less volatility. Both the PDFs and percentile spreads of the two release scenarios for production, consumption, and trade have marginal differences.

CONCLUSIONS

The overall results of this study show that while the abrupt release of excess Thailand rice stocks into the global market is probably not the most desirable course of action by the Thailand government, the net impacts on rice prices, trade, production, consumption appear to be manageable for the major rice players in global rice trade. In general, while rice producers will potentially face substantial losses, consumers will benefit considerably; and the net welfare changes are relatively moderate. Thailand, which implemented the PPP, will benefit the most in terms of net welfare. Considering the prohibitive costs of the PPP and the other problems that go with the program, the feasibility of either partial or full release of its excess stocks into the world market is an option that the Thailand government could explore. One important consideration, however, is the possible intervention of the World Trade Organization, if and when the country decides to implement such an action.

SIGNIFICANCE OF FINDINGS

This study is an initial attempt to analyze the impact of PPP, a controversial policy by Thailand, a major developing country player in the global rice market which has potential consequences on other developing countries. This is especially true for import-dependent and food-deficit countries. Results of this analysis enable rice stakeholders to better understand the response dynamics of the world rice economy on this kind of trade shock, with focus on selected major exporting and importing countries.

Rice is the most important food crop of the developing world and the staple food of more than half of the world's population (IRRI, 2013); and given that Arkansas is the major rice-producing state in the U.S. and nearly half of the state's annual rice crop is exported to the foreign market, it is quite important for Arkansas rice producers and other stakeholders to have a better understanding of the relevant market forces that drive both the state crop economy and the global rice market. Market prices received by Arkansas rice producers are primarily determined by the same factors that affect international trade.

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Table 1a. Impact on total world rice supply and utilization of 50% release of Thailand excess rice stocks, 2013-20.

Variable		Unit/ /year	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	10-Year Average
Area	Level	(1000 ha[a])	0.0	-937.1	-390.0	-338.5	-336.2	-334.0	-332.0	-324.1	-325.4	-304.2	-361.7
harvested	*Percent*		*0.0*	*-0.6*	*-0.2*	*-0.2*	*-0.2*	*-0.2*	*-0.2*	*-0.2*	*-0.2*	*-0.2*	*-0.2*
Production	Level	(1000 mt[b])	0.0	-3789.6	-1590.2	-1462.0	-1513.8	-1558.2	-1605.5	-1625.2	-1672.9	-1638.3	-1641.8
	Percent		*0.0*	*-0.8*	*-0.3*	*-0.3*	*-0.3*	*-0.3*	*-0.3*	*-0.3*	*-0.3*	*-0.3*	*-0.3*
Total	Level	(1000 mt)	5891.5	-93.8	922.2	1055.9	1071.0	1066.7	1049.7	1027.3	902.9	956.7	1385.0
consumption	*Percent*		*1.3*	*0.0*	*0.2*	*0.2*	*0.2*	*0.2*	*0.2*	*0.2*	*0.2*	*0.2*	*0.3*
Trade	Level	(1000 mt)	3430.2	1430.0	1224.3	1396.6	1437.6	1456.5	1469.3	1511.0	1435.8	1452.1	1624.3
	Percent		*9.3*	*3.9*	*3.2*	*3.5*	*3.6*	*3.7*	*3.6*	*3.6*	*3.4*	*3.4*	*4.1*
Ending stocks	Level	(1000 mt)	-5844	-9532	-12034	-14544	-17120	-19737	-22385	-25032	-27603	-30195	-18403
Percent		*-5.1*	*-7.7*	*-9.1*	*-10.4*	*-11.7*	*-12.9*	*-14.2*	*-15.3*	*-16.4*	*-17.6*	*-12.0*	

[a] ha = hectare which is 2.471 acres.

[b] mt = metric ton which is 1.1 tons.

Table 1b. Impact on world and U.S. rice prices of 50% release of Thailand excess rice stocks, 2013-2022.

Country		Unit/ /year	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	10-Year Average
Int'l reference price	Level	US$/mt[a]	-71.2	-0.5	-10.7	-11.5	-11.5	-11.5	-11.0	-11.5	-10.1	-9.9	-15.9
(Long-grain rice)	*Percent*		*-15.6*	*-0.1*	*-2.8*	*-3.0*	*-3.0*	*-2.9*	*-2.8*	*-2.8*	*-2.4*	*-2.5*	*-3.8*
U.S. No. 2	Level	US$/mt	-58.6	-3.3	-14.4	-23.8	-20.9	-22.0	-21.8	-22.4	-21.4	-21.6	-23.0
long-grain rice (fob Houston)	*Percent*		*-9.4*	*-0.6*	*-2.7*	*-4.3*	*-3.7*	*-3.9*	*-3.9*	*-4.0*	*-3.8*	*-3.8*	*-4.0*

[a] mt = metric ton which is 1.1 tons.

Table 1c. Impact on world rice net trade of 50% release of Thailand excess rice stocks, 2013-2022.

Country		Unit/ /year	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	10-Year Average
NET	**Level**	**(1000 mt[a])**	**3369.3**	**1424.0**	**1213.6**	**1386.4**	**1427.4**	**1446.2**	**1459.2**	**1500.7**	**1426.6**	**1442.7**	**1609.6**
EXPORTERS	*Percent*	*11.5*	*4.8*	*3.8*	*4.2*	*4.3*	*4.3*	*4.2*	*4.3*	*4.0*	*3.9*	*4.9*	
United States	Level	(1000 mt)	-39.2	-39.4	-117.0	-92.6	-103.1	-107.7	-112.0	-115.8	-120.0	-125.7	-97.3
	Percent	*-1.6*	*-1.7*	*-4.8*	*-3.6*	*-3.9*	*-4.1*	*-4.4*	*-4.5*	*-4.6*	*-4.9*	*-3.8*	
Thailand	Level	(1000 mt)	4928.6	1821.6	1965.5	2041.1	2101.0	2133.5	2161.8	2155.7	2069.0	2099.5	2347.7
	Percent	*79.3*	*30.4*	*33.5*	*34.5*	*35.9*	*35.9*	*35.9*	*35.2*	*32.7*	*33.6*	*38.7*	
Pakistan	Level	(1000 mt)	-251.7	-58.0	-140.1	-99.9	-101.3	-105.8	-111.5	-117.5	-113.3	-119.9	-121.9
	Percent	*-7.1*	*-1.6*	*-3.8*	*-2.6*	*-2.6*	*-2.7*	*-2.8*	*-2.9*	*-2.7*	*-2.9*	*-3.2*	
Vietnam	Level	(1000 mt)	-1014.3	30.8	-237.8	-228.3	-236.7	-239.3	-240.4	-176.4	-161.4	-165.8	-267.0
	Percent	*-13.3*	*0.4*	*-3.1*	*-3.0*	*-3.1*	*-3.1*	*-3.2*	*-2.3*	*-2.1*	*-2.1*	*-3.5*	
China	Level	(1000 mt)	-122.2	-17.1	-32.1	-35.1	-36.8	-38.7	-40.0	-42.7	-42.9	-45.1	-45.3
	Percent	*4.7*	*0.9*	*2.2*	*2.4*	*3.1*	*3.3*	*3.3*	*3.9*	*3.9*	*3.9*	*3.2*	
India	Level	(1000 mt)	67.2	-88.5	-32.6	-35.7	-41.5	-47.5	-53.0	-57.7	-64.6	-68.2	-42.2
	Percent	*1.0*	*-1.3*	*-0.4*	*-0.5*	*-0.5*	*-0.6*	*-0.6*	*-0.7*	*-0.8*	*-0.7*	*-0.5*	
NET	**Level**	**(1000 mt)**	**3369.3**	**1424.0**	**1213.6**	**1386.4**	**1427.4**	**1446.2**	**1459.2**	**1500.7**	**1426.6**	**1442.7**	**1609.6**
IMPORTERS	*Percent*	*11.5*	*4.8*	*3.8*	*4.2*	*4.3*	*4.3*	*4.2*	*4.3*	*4.0*	*3.9*	*4.9*	
Indonesia	Level	(1000 mt)	714.4	377.9	205.6	237.9	251.1	257.8	261.7	271.2	262.8	262.7	310.3
	Percent	*2313.9*	*49.8*	*25.2*	*32.3*	*42.6*	*65.6*	*42.0*	*52.2*	*54.9*	*39.5*	*271.8*	
Philippines	Level	(1000 mt)	578.3	193.1	157.8	229.8	247.1	257.7	268.2	282.4	281.1	295.0	279.1
	Percent	*42.7*	*14.7*	*13.2*	*20.0*	*24.5*	*34.9*	*51.8*	*97.9*	*973.0*	*184.1*	*145.7*	
Bangladesh	Level	(1000 mt)	6.0	621.5	290.4	321.0	320.4	314.6	303.9	285.2	268.4	238.1	296.9
	Percent	*0.6*	*82.4*	*27.0*	*24.5*	*21.5*	*22.9*	*21.3*	*18.0*	*16.3*	*15.7*	*25.0*	

Table 2a. Impact on total world rice supply and utilization of 100% release of Thailand excess rice stocks, 2013-2022.

Variable		Unit/ /year	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	10-Year Average
Area	Level	(1000 ha)	0.0	-1765.8	-777.7	-674.3	-665.4	-660.7	-655.7	-638.4	-639.3	-596.4	-706.5
Harvested	*Percent*		*0.0*	*-1.1*	*-0.5*	*-0.4*	*-0.4*	*-0.4*	*-0.4*	*-0.4*	*-0.4*	*-0.4*	*-0.4*
Production	Level	(1000 mt)	0.0	-7096.8	-3153.4	-2883.4	-2969.5	-3058.8	-3150.7	-3185.3	-3275.3	-3207.0	-3191.2
	Percent		*0.0*	*-1.5*	*-0.6*	*-0.6*	*-0.6*	*-0.6*	*-0.6*	*-0.6*	*-0.6*	*-0.6*	*-0.6*
Total	Level	(1000 mt)	11611.3	121.1	1914.9	2153.8	2199.1	2194.2	2162.8	2121.1	1880.4	1994.6	2835.3
Consumption	*Percent*		*2.5*	*0.0*	*0.4*	*0.4*	*0.4*	*0.4*	*0.4*	*0.4*	*0.4*	*0.4*	*0.6*
Exports	Level	(1000 mt)	6873.8	2879.2	2459.7	2785.1	2859.3	2891.8	2911.7	2992.4	2836.8	2864.6	3235.4
	Percent		*18.7*	*7.8*	*6.4*	*7.1*	*7.2*	*7.3*	*7.1*	*7.2*	*6.7*	*6.6*	*8.2*
Ending Stocks	Level	(1000 mt)	-11526	-18729	-23777	-28798	-33950	-39188	-44489	-49784	-54932	-60128	-36530
	Percent		*-10.1*	*-15.1*	*-18.0*	*-20.7*	*-23.3*	*-25.6*	*-28.1*	*-30.3*	*-32.6*	*-35.0*	*-23.9*

Table 2b. Impact on world rice prices of 100% release of Thailand excess rice stocks, 2013-2022.

Country		Unit/ /year	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	10-Year Average
Int’l reference price	Level	US$/mt	-127.7	-4.0	-21.6	-22.7	-22.7	-22.7	-21.6	-22.6	-19.9	-19.6	-30.5
(Long-grain rice)	*Percent*		*-27.9*	*-1.0*	*-5.6*	*-5.8*	*-5.8*	*-5.7*	*-5.4*	*-5.6*	*-4.8*	*-4.9*	*-7.2*
US No. 2	Level	US$/mt	-108.2	-8.9	-27.9	-45.7	-40.3	-42.8	-42.4	-43.7	-41.7	-42.2	-44.4
long-grain rice	*Percent*		*-17.4*	*-1.6*	*-5.2*	*-8.3*	*-7.2*	*-7.5*	*-7.5*	*-7.8*	*-7.4*	*-7.5*	*-7.7*
(fob Houston)													

Table 2c. Impact on world rice net trade of 100% release of Thailand excess rice stocks, 2013-2022.

Country		Unit/ /year	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	10-Year Average
NET	**Level**	**(1000 mt)**	**6759.5**	**2864.7**	**2437.6**	**2764.5**	**2838.8**	**2871.2**	**2891.4**	**2971.5**	**2818.3**	**2845.7**	3206.3
EXPORTERS	*Percent*		*23.1*	*9.6*	*7.7*	*8.4*	*8.5*	*8.6*	*8.3*	*8.4*	*7.9*	*7.7*	*9.8*
United States	Level	(1000 mt)	-78.6	-73.0	-221.5	-176.1	-199.1	-209.2	-218.6	-226.3	-235.2	-246.9	-188.4
	Percent		*-3.2*	*-3.1*	*-9.1*	*-6.9*	*-7.5*	*-8.0*	*-8.6*	*-8.7*	*-9.1*	*-9.7*	*-7.4*
Thailand	Level	(1000 mt)	9845.4	3618.5	3901.8	4046.8	4160.0	4219.1	4270.0	4252.7	4074.6	4130.9	4652.0
	Percent		*158.4*	*60.4*	*66.5*	*68.4*	*71.0*	*70.9*	*70.8*	*69.4*	*64.4*	*66.0*	*76.6*
Pakistan	Level	(1000 mt)	-539.7	-62.5	-276.4	-198.3	-199.9	-207.6	-218.6	-230.6	-221.4	-234.8	-239.0
	Percent		*-15.3*	*-1.8*	*-7.5*	*-5.2*	*-5.1*	*-5.2*	*-5.5*	*-5.8*	*-5.4*	*-5.7*	*-6.2*
Vietnam	Level	(1000 mt)	-2000.2	8.6	-467.8	-450.1	-467.5	-471.5	-473.1	-342.3	-312.7	-321.0	-529.8
	Percent		*-26.2*	*0.1*	*-6.0*	*-5.8*	*-6.1*	*-6.1*	*-6.4*	*-4.5*	*-4.0*	*-4.1*	*-6.9*
China	Level	(1000 mt)	-224.9	-37.3	-63.5	-68.7	-72.2	-76.0	-78.5	-83.9	-84.4	-88.8	-87.8
	Percent		*8.6*	*1.9*	*4.4*	*4.7*	*6.2*	*6.5*	*6.6*	*7.6*	*7.6*	*7.8*	*6.2*
India	Level	(1000 mt)	128.9	-166.7	-65.3	-71.4	-82.4	-94.2	-105.3	-114.7	-128.3	-135.7	-83.5
	Percent		*1.9*	*-2.5*	*-0.9*	*-0.9*	*-1.1*	*-1.3*	*-1.2*	*-1.4*	*-1.6*	*-1.4*	*-1.0*
NET	**Level**	**(1000 mt)**	**6759.5**	**2864.7**	**2437.6**	**2764.5**	**2838.8**	**2871.2**	**2891.4**	**2971.5**	**2818.3**	**2845.7**	**3206.3**
IMPORTERS	*Percent*		*23.1*	*9.6*	*7.7*	*8.4*	*8.5*	*8.6*	*8.3*	*8.4*	*7.9*	*7.7*	*9.8*
Indonesia	Level	(1000 mt)	1373.2	728.9	418.3	471.7	495.0	507.5	514.6	533.5	516.6	516.1	607.6
	Percent		*4448.0*	*96.1*	*51.3*	*64.0*	*84.0*	*129.1*	*82.5*	*102.6*	*107.9*	*77.7*	*524.3*
Philippines	Level	(1000 mt)	1152.1	396.5	319.4	454.2	489.1	509.8	530.1	557.9	554.7	581.8	554.6
	Percent		*85.1*	*30.2*	*26.6*	*39.6*	*48.4*	*69.1*	*102.4*	*193.5*	*1919.9*	*363.0*	*287.8*
Bangladesh	Level	(1000 mt)	11.7	1187.0	585.6	638.1	633.2	619.8	596.1	556.1	519.4	456.2	580.3
	Percent		*1.1*	*157.3*	*54.5*	*48.7*	*42.5*	*45.1*	*41.7*	*35.1*	*31.6*	*30.2*	*48.8*

Table 3a. Change in producer surplus at 50% release of Thailand excess rice stocks by country and by year, 2013-2022.

Country	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	10-year ave
	($ million)										
Thailand	0	0	0	0	0	0	0	0	0	0	0
Vietnam	(1,638)	(12)	(267)	(297)	(309)	(323)	(320)	(184)	(163)	(162)	(368)
Philippines	(1,056)	(8)	(165)	(181)	(186)	(191)	(188)	(202)	(182)	(185)	(254)
Indonesia	(3,037)	(22)	(471)	(514)	(523)	(537)	(524)	(561)	(504)	(509)	(720)
U.S.	(250)	(16)	(67)	(111)	(97)	(101)	(98)	(101)	(94)	(93)	(103)
China	(8,655)	125	(977)	(1,113)	(1,064)	(1,091)	(1,040)	(1,112)	(1,011)	(1,043)	(1,698)
India	(603)	2	(99)	(109)	(112)	(111)	(108)	(113)	(97)	(101)	(145)

Table 3b. Change in consumer surplus at 50% release of Thailand excess rice stocks by country and by year, 2013-2022.

Country	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	10-year ave
	($ million)										
Thailand	631	207	297	325	344	366	376	398	403	409	376
Vietnam	1,207	8	193	217	227	237	236	135	119	119	270
Philippines	1,185	8	182	199	202	203	197	207	183	188	275
Indonesia	3,139	22	481	523	532	544	533	570	511	518	737
U.S.	169	9	41	68	60	63	63	64	60	61	66
China	8,654	(122)	964	1,102	1,055	1,084	1,044	1,115	1,022	1,062	1,698
India	566	(2)	93	102	105	104	101	105	91	93	136

Table 3c. Net welfare changes at 50% release of Thailand excess rice stocks by country and by year, 2013-2022.

Country	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	10-year ave
	($ million)										
Thailand	631	207	297	325	344	366	376	398	403	409	376
Vietnam	(431)	(3)	(74)	(81)	(82)	(86)	(84)	(49)	(44)	(44)	(98)
Philippines	129	1	16	17	16	12	9	5	1	3	21
Indonesia	102	0	9	10	9	7	10	9	7	10	17
U.S.	(81)	(6)	(26)	(43)	(37)	(38)	(35)	(36)	(34)	(33)	(37)
China	(0)	3	(13)	(11)	(8)	(8)	5	4	12	20	0
India	(37)	0	(6)	(7)	(7)	(7)	(7)	(8)	(7)	(7)	(9)

Table 4a. Changes in producer surplus at 100% release of Thailand excess rice stocks by country and by year, 2013-2022.

Country	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	10-year ave
	($ million)										
Thailand	0	0	0	0	0	0	0	0	0	0	0
Vietnam	(2,937)	(96)	(538)	(587)	(611)	(638)	(631)	(364)	(322)	(320)	(704)
Philippines	(1,889)	(64)	(333)	(357)	(367)	(377)	(371)	(398)	(359)	(365)	(488)
Indonesia	(5,410)	(178)	(949)	(1,012)	(1,033)	(1,059)	(1,032)	(1,105)	(995)	(1,003)	(1,378)
U.S.	(451)	(42)	(129)	(211)	(186)	(194)	(189)	(194)	(182)	(181)	(196)
China	(15,179)	(103)	(1,956)	(2,186)	(2,106)	(2,162)	(2,059)	(2,197)	(2,009)	(2,068)	(3,203)
India	(1,155)	(23)	(203)	(219)	(224)	(223)	(217)	(227)	(195)	(201)	(289)

Table 4b. Changes in consumer surplus at 100% release of Thailand excess rice stocks by country and by year, 2013-2022.

Country	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	10-year ave
	($ million)										
Thailand	1,238	567	759	853	932	1,019	1,079	1,162	1,217	1,255	1,008
Vietnam	2,205	69	390	429	450	470	467	268	236	234	522
Philippines	2,170	70	367	394	400	403	390	410	364	373	534
Indonesia	5,686	181	971	1,036	1,054	1,076	1,054	1,126	1,013	1,025	1,422
U.S.	314	25	80	131	116	123	123	125	117	119	127
China	15,391	101	1,934	2,169	2,094	2,152	2,073	2,210	2,037	2,113	3,227
India	1,086	22	191	205	211	208	202	211	181	186	270

Table 4c. Net welfare changes at 100% release of Thailand excess rice stocks by country and by year, 2013-2022.

Country	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	10-year ave
	($ million)										
Thailand	1,238	567	759	853	932	1,019	1,079	1,162	1,217	1,255	1,008
Vietnam	(732)	(27)	(148)	(158)	(161)	(168)	(164)	(96)	(86)	(86)	(183)
Philippines	280	6	35	36	33	25	19	13	4	8	46
Indonesia	276	3	22	23	21	17	22	21	17	22	44
U.S.	(136)	(16)	(49)	(80)	(70)	(71)	(67)	(68)	(64)	(62)	(68)
China	212	(2)	(22)	(16)	(12)	(10)	14	13	28	44	25
India	(69)	(1)	(12)	(14)	(13)	(15)	(15)	(16)	(13)	(14)	(18)

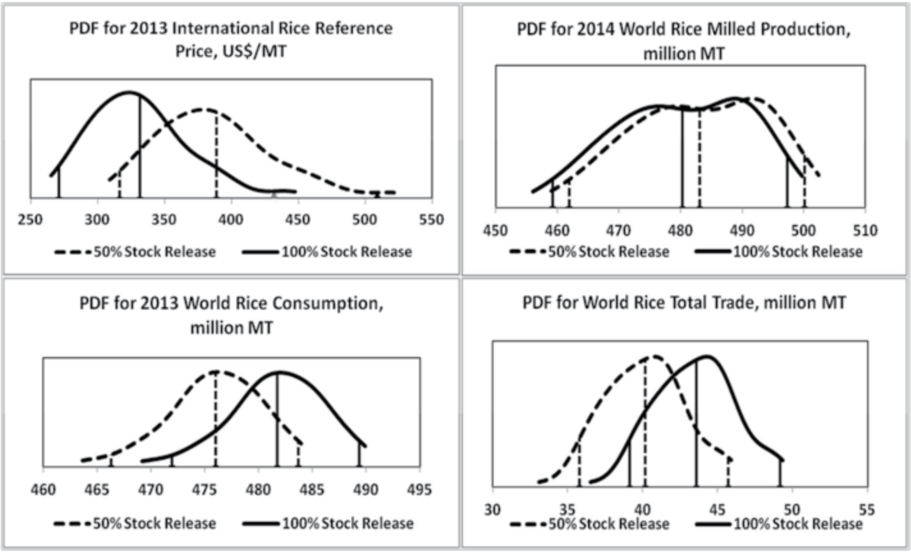
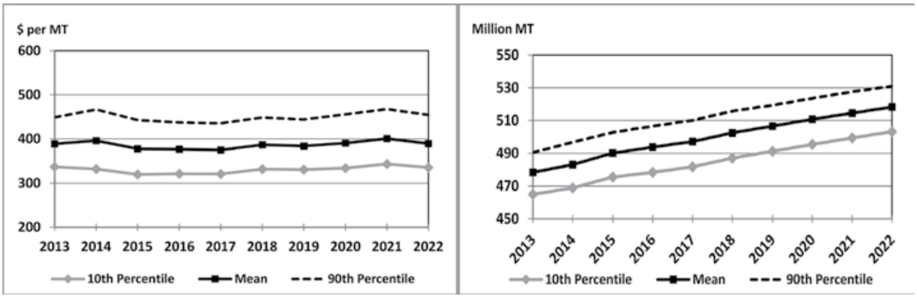
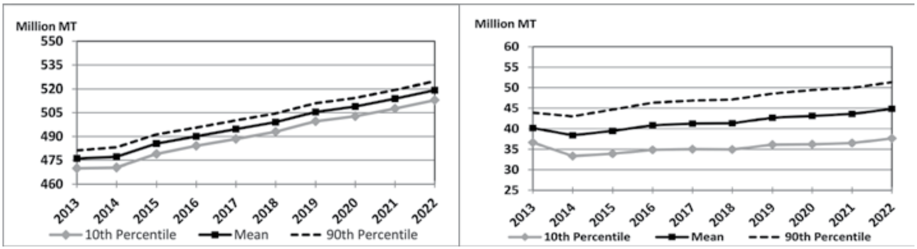


Fig. 1. Approximate probability distribution functions at 50% and 100% release of Thailand excess rice stocks.

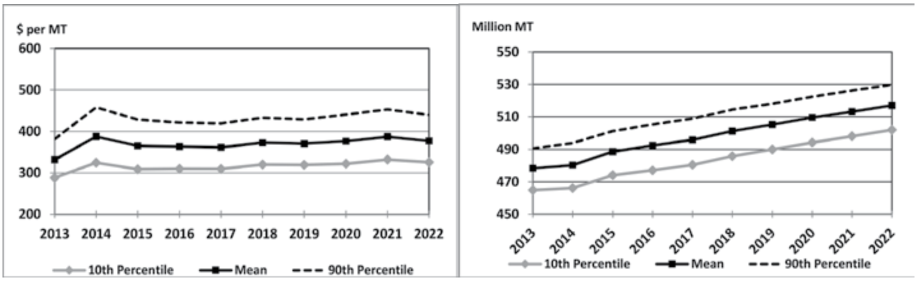


Stochastic World Consumption at 50% Thailand Stock Release Stochastic World Consumption at 50% Thailand Stock Release

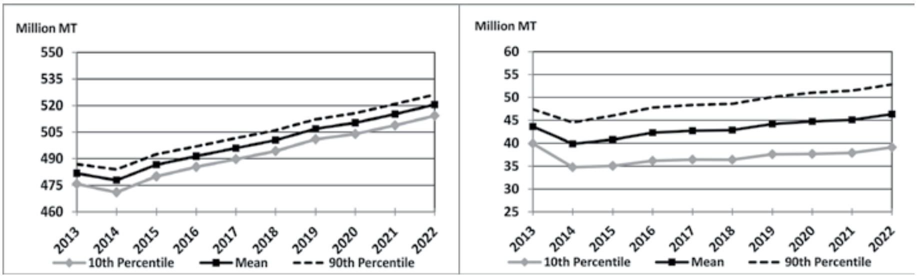


Stochastic World Consumption at 50% Thailand Stock Release Stochastic World Consumption at 50% Thailand Stock Release

Fig. 2. Tenth and 90th percentiles of the stochastic distribution at 50% release of Thailand excess rice stocks, 2013-2022.



Stochastic World Consumption at 100% Thailand Stock Release Stochastic World Consumption at 100% Thailand Stock Release



Stochastic World Consumption at 100% Thailand Stock Release Stochastic World Consumption at 100% Thailand Stock Release

Fig. 3. Tenth and 90th percentiles of the stochastic distribution at 100% release of Thailand excess rice stocks, 2013-2022.

World Rice Outlook: International Rice Baseline Projections, 2013-2023

E.J. Wailes and E.C. Chavez

ABSTRACT

The U.S. Farm Bill 2014 was signed into law by the President on 7 February 2014. This legislation is considered to be more complex than previous Farm Bills. Under the new law, commodity producers have to make their own decisions; and each producer will have to pay considerable attention to details. Producers have to develop their own perspective on market price paths over the life of the farm bill, using available projections from various agencies. This makes baseline projections for covered commodities more important this year than ever. This study presents a set of deterministic baseline projections for international rice, a covered commodity in the new Farm Bill. Results show that over the 10-year baseline period, world rice output grows at 1.01%/year with 0.80% coming from yield improvement and 0.21% coming from slight growth in area harvested. Driven solely by annual population growth of 1.03%, global rice consumption gains 1.02% annually as global average per capita rice use declines by 0.01%. With growth in production in close tandem with gains in consumption, international prices remain relatively stable with only a slight growth, as net trade grows at 1.93%/year.

INTRODUCTION

The U.S. Farm Bill 2014 was passed by the House of Representatives on 28 January 2014, by the Senate on 4 February 2014; and signed into law by the President on 7 February 2014. The bill covers the 5-year period 2014-2018, and includes 12 titles. Title I covers Commodities which includes the price and revenue support programs: Price Loss Coverage (PLC) and Agricultural Risk Coverage (ARC). These two programs replaced the Direct Payment, Counter-Cyclical Payment (CCP), and Average

Crop Revenue Election (ACRE) programs of the 2008 Farm Bill which were repealed under the new law. An interpretation of the main features of Title I can be found in a brief on 'Commodity program options in the 2014 farm bill' recently prepared by Wailes et al. (2014) under the Division of Agriculture Research and Extension, University of Arkansas. The original source of the information is the Conference Report of the 113th Congress (2014).

The 2014 Farm Bill is considered more complex and requires more attention by each producer. Under the new law, commodity producers have to make their own decisions that will affect their farming operations for at least 5 years. For one, the producers have to decide from the new programs or a possible combination of programs. They need to collect farm and county yield data, and decide on whether to retain their base acres or take advantage of the one-time reallocation of base acres, and how to assign their generic (cotton) base acres in a way that will most likely be beneficial to them. Most importantly, they have to develop their own perspective on market price paths over the life of the farm bill, using projections from various agencies like the Food and Agricultural Policy Research Institute (FAPRI), U.S. Department of Agriculture (USDA), Congressional Budget Office (CBO), and others. Hence, producer decisions largely depend on price expectations, not just for this year but over the next 5 or possibly more years in the event the bill is extended as experienced in the past. As such, baseline projections are more important this year than ever.

The need for reliable and reasonable projections of national commodity prices becomes more important as the new Farm Bill 2014 repealed the direct payments which were fixed and de-coupled from the market, and introduced new programs that provide only probable payments based on the differences between market prices and reference prices in the case of PLC, and between actual revenues and benchmark revenues in the case of ARC. Furthermore, it is beneficial for U.S. rice producers to have a better understanding of the role of U.S. rice in the global rice economy. The degree of U.S. rice price integration/insulation relative to the Asian markets is no longer just an academic question but has real implications for decisions on PLC/ARC choices.

Rice is the most important food crop of the developing world and the staple food of more than half of the world's population, accounting for more than 20% of daily caloric requirement (IRRI, 2013). The U.S. is one of the five top players in the international rice trade, exporting nearly half of its total rice output. Thus U.S. rice prices are heavily influenced by factors prevailing in the global rice economy. The international rice prices are determined by the supply, demand, trade, and stocks of rice as well as policies in the U.S. and other major rice exporting and importing countries. This study provides a summary of 10-year baseline projections for the world rice markets. It is an assessment of the primary drivers of rice prices and supply and demand over the next decade.

This research benefitted from input information provided by FAPRI at the University of Missouri which included projected costs and net returns for major U.S. commodity crops, and the macro data. The historical rice data are obtained from the USDA-PS&D online dataset (USDA-FAS, 2014). Sources of recent rice industry information include U.S. Rice Outlook as of January 2014 (Childs, 2014) and various issues of USDA-FAS Attache reports (USDA-FAS, 2013-2014). However, all the results presented in this report remain the responsibility of the authors. The baseline numbers presented are average projections of what could happen if basic assumptions used in the analysis hold true.

PROCEDURES

The baseline estimates presented in this report are generated using the Arkansas Global Rice Model (AGRM), a partial equilibrium, non-spatial, multi-country statistical simulation and econometric analytical framework developed and maintained by the University of Arkansas Global Rice Economics Program (AGREP) with the Department of Agricultural Economics and Agribusiness at the University of Arkansas, Fayetteville. The model is disaggregated into five world regions (Africa, the Americas, Asia, Europe, and Oceania) and covers 51 countries/regions that can be used to analyze short-term and long-term impacts of price, supply, and demand scenarios in the global rice market. Each country and regional model includes a supply sector, a demand sector, a trade, stocks and price linkage equations. The model links countries through prices and trade. The equilibrium international rice reference prices are obtained by generating a balanced trade, i.e., net rice exports = net rice imports.

Other details and the theoretical structure and the general equations of the Arkansas Global Rice Model can be found in the online documentation by Wailes and Chavez (2011). The baseline assumes the following: continuation of existing policies, current macroeconomic variables, no new WTO trade reforms, and average weather conditions.

RESULTS AND DISCUSSION[1]

Thailand's paddy pledging program (PPP) which was implemented in October 2011 as an election promise of the then newly elected Prime Minister has remained in place in the country and continues to be an important concern in the international rice market. Recall that the program provides price supports to the rice producers which are as much as 50% higher than prevailing market prices (Wailes and Chavez, 2013). This results in separation between Thailand's and other Asian rice export prices. The country lost leadership in global rice trade and its rice exports plunged 40% in 2011; and rice stockpiles doubled.

Another consequence of this situation is that the prevailing high Thai rice prices have diminished their usefulness as the reference of international rice prices. As such, the equilibrium rice international reference prices currently generated by the AGRM are closer to the prevailing export prices of Vietnam and India, and substantially lower than the quoted Thai prices (Wailes and Chavez, 2013) This is supported by the fact that the global rice market is now dominated by India and Vietnam, with relatively dependable supplies also coming from Pakistan, Cambodia, and Myanmar.

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[1] Although complete baseline projections for supply and demand variables are generated for all 50 countries/regions covered by AGRM, only selected variables are included in this report to save space.

While operational controversies on the PPP abound, the most pressing issue recently is the inability and failure of the Thailand government to pay the farmers for their pledged paddy. So far, the rice purchases of the program have reportedly cost US$22 billion, excluding administrative costs, which has exceeded the original US$16 billion authorized by the government. To put a lid on program losses, the government decided to impose limits on the number of pledges for each farm household—from the original unlimited tonnage to a maximum of 350,000 baht (1 baht = $0.031) equivalent tonnage in the main-season and 300,000 baht equivalent tonnage in the off-season. The government has also reduced the intervention prices for the off-season crop by 13% (USDA-FAS, 2013a).

With mounting stocks in Thailand, combined with large rice stocks from India, the global rice market is expected to face an abundant supply of rice over the projection period—with a consequent dampening effect on international rice prices. This situation will certainly benefit the food-deficit rice-importing countries in the developing world but could have uncertain impact on rice producers and exporters. A recent study by Wailes et al. (2014) looks at the impacts to major players in global rice trade in the event Thailand releases its excessive stocks to the world market at subsidized prices. Part of the analysis shows the average impact of a one-time shock on the model. Under the 50% excess stocks release scenario, global rice net trade expands by 11.5% and the long-grain international reference price declines by16%. The results under the 100% excess stocks release scenario are almost double those under the 50%, with global rice net trade expanding by 23.1%, and the long-grain rice international reference price declining by 28%. The U.S. long-grain rice export price, on the other hand, declines by 9.4% and 17.4% under the two scenarios, respectively.

Over the baseline period, as growth in production remains in close tandem with gains in consumption, prices remain relatively stable with long-grain rice international reference price remaining within the range $400-$412/metric tons (mt). While global rice prices grow slightly, U.S. rice export prices are expected to decline over the same period, as the wide U.S. price margin over Asian prices narrows from the unsustainably high level of $200 currently to a more historically reasonable level of about $80 by the end of the projection period. United States average farm prices also follow the declining trend. There are several factors that can potentially drive the high U.S. prices downward, going forward. These include rice surpluses in India and Thailand; significant investment in production and processing capacity on Mekong Delta in Vietnam; and productivity gains from hybrids and GRiSP research, positively impacting Asian and African rice economies; increasing competition with the U.S. on quality with competitors; and strong trends in diet diversification in many parts of the world.

Detailed results of the analysis for the world and the U.S. rice showing 12 years of information (2012-2023) are presented in Tables 1 through 5. Over the baseline projection period, world rice output grows at 1.01%/year, reaching 525.0 million metric tons (mmt) in 2023 with 0.80% coming from yield improvement and 0.21% coming from growth in area harvested. The detailed projected yields by country are presented in Table 5. Driven solely by population growth, global rice consumption gains 1.02% annually, reaching nearly 522.0 mmt in 2023—with population growing at 1.03% but average world rice per capita use declining very slightly by 0.01% (Tables 2 and 4).

Net trade grows at 1.94%/year, reaching nearly 39.0 mmt by 2023. International long-grain rice prices are projected to increase only slightly by 0.21% annually, as major consuming countries are expected to focus more towards self-sufficiency in rice and increase the use of high-yielding hybrids and other improved production technologies. Medium-grain rice prices are projected to remain relatively stronger, i.e. with an annual growth of 0.76%/year as traded volumes remain small compared to long-grain (Table 1).

The international rice market is characterized by high volatility because it is thinly traded and highly concentrated, in addition to the price inelastic supply and demand of rice. In addition, the international rice market is subject to high levels of domestic and trade policy distortions in many countries. There is also very high concentration among leading rice exporters, with the top five countries (India, Vietnam, Thailand, Pakistan, and the U.S.) accounting for 90% of global net exports (Table 1).

Despite the country's very unpopular and controversial PPP, Thailand is projected to resume its strong presence in the global rice market. Reports indicate that the country is increasing its efforts on attracting government-to-government rice deals to unload their excessive rice stockpile (USDA-FAS, 2013-2014). While the Thai government is expected to incur substantial financial losses in the short-term as it ships high-priced rice in the global market at competitively low prices, the country is expected to recoup its global position as top rice exporter over the baseline period given its good infrastructure resources and concerted focus on developing and maintaining a strong presence in the branded high quality rice. The popularity of the country's 'Thai Hom Mali'-branded Jasmine rice which is a fragrant long-grain rice, is quite strong among Asians.

India became the top rice exporter in 2011/12 and 2012/13 marketing years, and is projected to still be the leading rice exporter in 2013/14, with total shipments in all those years exceeding 10.0 mmt (Table 1). However, India's exports are projected to decline steadily from this high level to about 8.0 mmt by 2023, as the country implements its National Food Security Bill which was signed into law on 12 September 2013 (USDA-FAS, 2013b), creating an entitlement for eligible beneficiaries to receive 5 kilograms of rice, wheat, or coarse grain (millet) at highly subsidized prices. This reportedly covers 50% of the urban and 75% of the rural populations which translate to about 820 million people (USDA-FAS, 2014).

India's net exports in 2012/13 were 10.9 mmt, followed by Vietnam with 7.1 mmt, and Thailand with 6.1 mmt (Table 1). Vietnam rice exports are projected to catch up with India's level by 2021/23 at net exports of 8.0 mmt. Thailand, on the other hand, is projected to catch up with India's exports by 2018/19 at about 8.7 mmt level, and resume rice export leadership thereafter. Rice exports of the U.S. remain relatively flat around 2.3 mmt over most of the projection period, given only slight growth in both area and average yields and expected increasing competition from Asian exporters (Table 3).

Cambodia and Myanmar are two countries with strong potential as rice exporters in the years to come, both with rice exports projected to expand steadily as production continues to exceed consumption. Cambodia's rice exports are projected to grow at

9.2% annually, reaching 2.4 mmt in 2023 (Table 1), as its total production gains 3.8%/year while its total consumption grows slower at 1.9%. Rice exports of Myanmar, on the other hand, are projected to grow at 6.4%/year, reaching 1.3 mmt in 2023, with its total production and consumption growing at 1.6% and 1.2%/year, respectively.

Global net rice exports total 31.7 mmt in 2012 and are projected to grow by a total of 7.1 mmt over the baseline period (2012-2023), or about 1.9% annually, of which nearly 70% is accounted for by Thailand, as the country expands its exports and regains its top position in global rice trade (Table 1). On the other hand, world rice imports are dominated by 10 countries that account for nearly 50% of total imports over the baseline period. They are Nigeria, People's Republic of China, Iran, Indonesia, Iraq, Saudi Arabia, Bangladesh, Cote d'Ivoire, the Philippines, and Malaysia. In terms of volume growth of rice imports, 47% is projected to come from two major Asian importing countries of Bangladesh and Indonesia combined, 18% from the 15-member Economic Community of West African States (ECOWAS), and 14% from the Middle East. These countries/regions account for a total of 79% share in expansion of global net imports over the same period. U.S. total rice imports are projected to increase by 245 thousand mt, equivalent to a growth of 2.4%/year.

While the global rice harvested area will grow by nearly 5.0 million hectares on a net basis over the baseline period, some notable changes are projected for a number of countries (Table 2). There is a total expansion of 4.0 million hectares of rice in the five countries of Nigeria, India, Pakistan, Bangladesh, and Myanmar combined; and a total expansion of 2.0 million hectares in ECOWAS. However, the rice area of the People's Republic of China is projected to decline by nearly 1.0 million hectares due to a shift to substitute crops and irrigation constraints. The U.S. rice area is projected to remain relatively flat over the projection period at around 1.1 million hectares due to water constraints and an increasingly competitive market environment. Other constraints to potential rice expansion include competing uses of limited land and water; farm demographics — with farmers getting older and labor moving from farm to cities; uncertain calamities due to climate change; changing consumer tastes towards healthy foods; and emerging environmental issues on the rice carbon footprint.

The global milled rice output is projected to grow by a total of 51.1 mmt over the period 2012-2023. By volume, about 27% of the expected growth over the same period will come from India; nearly 44% from with the seven countries of China, Bangladesh, Indonesia, Cambodia, Myanmar, the Philippines, and Vietnam combined; and 11% from ECOWAS. Total U.S. rice production is projected to increase by about 573 thousand mt over the same period with slight gains in area and yields.

Rice consumption is driven by income, population, and other demographics. Rising incomes dampen rice demand in some Asian countries where rice is considered an inferior good. 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 projection period, global rice consumption will grow by 56.0 mmt (net) with nearly 31% accounted for by India; about 30% by the five countries of Bangladesh, Indonesia, China, the Philippines, and Vietnam combined; and 11% by ECOWAS

(Table 2). While China's rice per capita use continues to decline at 0.30% per year, the country's population grows at 0.44% annually resulting in net growth in total rice consumption of 0.14% annually, reaching 147.4 mmt in 2023. United States total rice consumption increases by nearly 847 thousand mt over the same period, with annual growth rates of 1.26% in per capita use and 0.76% in population.

Global rice stocks will expand by 39 mmt over the projection period, from 107 mmt in 2012 to 146 mmt in 2023, with stocks-to-use ratio increasing from 0.23 to 0.28 over the same period (Table 2). Two countries account for over 90% of this rice global stock build-up. The People's Republic of China accounts for 58%, as the country takes advantage of low global prices and maintains its strong rice purchases. Thailand accounts for 35%, as the country faces challenges in releasing its excessive rice stockpile into the global market (Wailes and Chavez, 2014).

Overall assessment of the global rice economy in this baseline over the next decade indicates that, under assumed normal average weather conditions, the world is projected to face abundant rice supplies due to current surpluses, increased productivity, use of modern growing and processing technologies, and a focus on self-sufficiency in rice. Most likely, all of this points to an environment of relatively low and stable global rice prices. Detailed analysis is reported in Wailes and Chavez, 2014.

SIGNIFICANCE OF FINDINGS

Baseline projections of commodity prices, supply, and demand have never been more important for agricultural stakeholders than with the signing into law of U.S. Farm Bill 2014. Under the new law, commodity producers have to make their own decisions on the new programs or a possible combination of programs. Most importantly, they have to develop their own perspective on market dynamics over the next five or more years. Specifically, it would be very beneficial for Arkansas rice stakeholders to have a better 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 45% of the country's rice output; and nearly half of Arkansas annual rice crop is exported to the foreign markets. 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. The baseline results presented in this report can be considered as a synthesis of the impacts of these factors, and serve to indicate what could happen over the next decade. The projections can also be used as a baseline for evaluating and comparing alternative macroeconomic, policy, weather, and technological scenarios.

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Table 1. Projected rice net trade by country and prices, 2012-2023.

	12/13	13/14	14/15	15/16	16/17	17/18	18/19	19/20	20/21	21/22	22/23	23/24	Percent growth	Total qty change
	----------(thousand metric tons)----------												(2012-23)	(2012-23)
Net exporters														
Argentina	570	574	606	638	656	713	755	783	827	871	916	948	5.11%	378
Australia	360	373	398	407	438	445	447	456	441	459	458	421	1.80%	61
Cambodia	970	1,007	1,146	1,342	1,581	1,641	1,880	1,997	2,105	2,224	2,306	2,375	9.15%	1,405
People's Rep. of China	-2,759	-3,050	-2,504	-2,322	-2,268	-2,138	-2,043	-1,971	-1,975	-1,783	-1,711	-1,616	-5.02%	1,143
Egypt	800	839	870	920	939	992	987	984	971	968	970	984	1.67%	184
India	10,900	10,029	9,647	9,324	9,149	8,886	8,733	8,564	8,374	8,059	8,088	7,987	-2.54%	-2,913
Myanmar (Burma)	750	677	701	774	996	1,153	1,218	1,169	1,163	1,207	1,250	1,259	6.35%	509
Pakistan	3,255	3,349	3,525	3,748	3,833	3,571	3,558	3,563	3,649	3,712	3,769	3,834	1.01%	579
Thailand	6,100	7,761	7,648	7,777	7,989	8,192	8,711	9,264	9,776	10,294	10,660	10,973	4.67%	4,873
United States	2,731	2,407	2,305	2,298	2,337	2,395	2,330	2,334	2,366	2,372	2,316	2,328	-0.62%	-403
Uruguay	875	910	928	944	969	984	993	997	999	1,003	1,015	1,038	1.33%	163
Vietnam	7,100	7,116	7,259	7,509	7,509	7,637	7,738	7,911	7,962	8,090	8,176	8,225	1.44%	1,125
Total net exports[a]	**31,652**	**31,991**	**32,528**	**33,360**	**34,129**	**34,470**	**35,308**	**36,051**	**36,659**	**37,476**	**38,214**	**38,756**	**1.93%**	**7,104**
Net importers														
Bangladesh	35	313	961	1,376	1,418	1,636	1,573	1,575	1,590	1,594	1,855	1,918	25.34%	1,883
Brazil	0	-84	-337	-363	-314	-347	-330	-310	-272	-253	-247	-217	-	-217
Brunei Darussalam	45	47	48	49	50	51	53	54	55	56	57	58	2.21%	13
Cameroon	500	528	488	485	488	502	505	520	545	543	551	533	0.92%	33
Canada	350	358	376	420	435	448	461	471	481	491	500	514	3.58%	164
China - Hong Kong	425	438	445	447	453	458	463	468	473	477	481	494	1.18%	69
Colombia	300	276	325	342	386	405	422	425	423	421	426	427	3.92%	127
Cote d'Ivoire	1,270	1,330	1,329	1,265	1,246	1,248	1,255	1,229	1,223	1,247	1,193	1,207	-0.76%	-63
European Union-27	1,190	1,132	1,155	1,147	1,148	1,142	1,134	1,128	1,104	1,092	1,085	1,059	-0.80%	-131
Ghana	575	600	631	653	672	696	757	773	807	824	835	854	3.83%	279
Guinea	260	259	269	225	217	218	235	228	237	266	257	276	0.33%	16

continued

Table 1. Continued.

	12/13	13/14	14/15	15/16	16/17	17/18	18/19	19/20	20/21	21/22	22/23	23/24	Percent growth	Total qty change
	---(thousand metric tons)---												(2012-23)	(2012-23)
Net importers (continued)														
Indonesia	650	1,717	2,117	2,074	2,052	1,715	1,701	1,897	1,874	2,011	2,137	2,085	4.90%	1,435
Iran	1,900	1,720	1,710	1,731	1,839	1,862	1,921	1,961	1,962	2,008	2,045	2,045	1.53%	145
Iraq	1,450	1,446	1,438	1,481	1,534	1,595	1,647	1,696	1,747	1,803	1,856	1,908	2.84%	458
Japan	500	482	482	482	482	482	482	482	482	482	482	482	-0.14%	-18
Kenya	360	449	461	533	549	587	662	711	762	801	830	863	7.89%	503
Lao PDR	30	15	-23	-25	-31	-68	-101	-137	-170	-196	-234	-235	-	-265
Liberia	260	240	246	257	286	303	327	339	357	375	382	406	5.13%	146
Malaysia	900	1,131	1,065	1,066	1,091	1,118	1,141	1,166	1,191	1,222	1,240	1,262	2.22%	362
Mali	100	158	138	45	15	-52	-64	-90	-96	-108	-144	-143	-	-243
Mexico	723	747	750	762	777	797	819	839	860	878	888	890	2.05%	167
Mozambique	485	533	472	507	509	520	558	574	621	654	705	729	3.82%	244
Nigeria	2,900	2,944	2,984	2,987	2,945	2,924	3,015	3,012	3,083	3,109	3,121	3,144	0.68%	244
Philippines	1,400	1,474	1,412	1,406	1,345	1,220	1,146	1,064	969	848	762	649	-6.95%	-751
Saudi Arabia	1,205	1,272	1,311	1,355	1,401	1,437	1,467	1,501	1,531	1,560	1,584	1,611	2.56%	406
Senegal	1,130	1,092	1,048	1,075	1,082	1,087	1,100	1,105	1,112	1,114	1,114	1,115	0.25%	-15
Sierra Leone	275	353	353	349	352	341	337	331	322	315	298	286	-0.87%	11
Singapore	350	361	364	372	375	376	377	378	378	377	375	386	0.61%	36
South Africa	890	949	931	930	943	952	968	962	976	1,004	994	1,035	1.02%	145
South Korea	508	410	409	409	409	409	409	409	409	409	409	409	-0.85%	-99
Taiwan	123	123	123	123	123	123	123	123	123	123	123	123	0.00%	0
Tanzania	170	236	277	302	298	315	352	369	400	444	469	494	8.50%	324
Turkey	211	280	281	287	282	298	301	269	275	286	282	280	1.04%	69
Other Africa	2,780	2,732	2,775	2,864	3,025	3,183	3,306	3,415	3,475	3,608	3,683	3,750	3.26%	970
Other Americas	1,430	1,847	1,556	1,755	1,830	1,899	1,951	2,060	2,068	2,052	1,994	1,953	2.57%	523
Other Asia	2,698	2,632	2,754	2,697	2,854	2,930	3,044	3,148	3,220	3,336	3,462	3,539	2.84%	841
Other Europe	242	299	241	239	257	253	265	269	277	302	324	347	2.55%	105
Other Oceania	247	259	274	287	300	313	326	339	352	364	376	388	4.19%	142
ECOWAS 7[b]	1,160	1,111	1,126	1,196	1,269	1,363	1,467	1,577	1,698	1,819	1,947	2,081	6.24%	921

continued

Table 1. Continued.

	12/13	13/14	14/15	15/16	16/17	17/18	18/19	19/20	20/21	21/22	22/23	23/24	Percent growth	Total qty change
	----(thousand metric tons)----												(2012-23)	(2012-23)
Net importers (continued)														
Residual	1,625	-223	-235	-236	-264	-269	-268	-277	-262	-283	-282	-245	-	-1,871
Total net imports	**31652**	**31991**	**32528**	**33360**	**34129**	**34470**	**35308**	**36051**	**36659**	**37476**	**38214**	**38756**	**1.93%**	**7,104**
	---- (U.S. dollar/metric ton)----												(2012-23)	(2012-23)
International Rice Reference Price	410	393	401	402	403	403	404	404	406	407	410	412	0.21%	2
U.S. FOB[c] Gulf Ports	630	606	559	545	532	517	519	511	511	509	498	494	-1.93%	-136
U.S. No. 2 Medium FOB CA	712	636	670	680	688	693	698	704	711	718	722	728	0.76%	16

[a] Total net exports are the sum of all positive net exports and negative net imports.

[b] ECOWAS 7 = Economic Community of West African States.

[c] FOB = freight on board.

Table 2. Projected world rice supply and utilization, 2012-2023.

	12/13	13/14	14/15	15/16	16/17	17/18	18/19	19/20	20/21	21/22	22/23	23/24	Percent growth	Total qty change
						(thousand hectares)							(2012-23)	(2012-23)
Area harvested	157,677	160,418	160,457	161,152	161,436	161,700	161,949	162,076	162,251	162,472	162,511	162,644	0.21%	4,967
						(metric tons/hectare)							(2012-23)	(2012-23)
Yield	2.98	2.95	3.00	3.03	3.06	3.08	3.11	3.13	3.16	3.18	3.20	3.23	0.80%	0
						(thousand metric tons)							(2012-23)	(2012-23)
Production	469,992	473,470	482,068	488,336	493,434	498,201	503,971	507,689	512,154	516,374	519,523	525,080	1.01%	55,088
Beginning stocks	104,467	107,200	106,526	110,363	115,368	120,285	124,955	129,905	133,721	137,602	140,941	143,015	3.22%	38,549
Domestic supply	574,458	580,669	588,594	598,698	608,802	618,486	628,926	637,594	645,874	653,975	660,464	668,095	1.44%	93,637
Consumption	465,634	474,370	478,466	483,566	488,781	493,799	499,290	504,151	508,534	513,317	517,731	521,877	1.02%	56,243
Ending stocks	107,200	106,526	110,363	115,368	120,285	124,955	129,905	133,721	137,602	140,941	143,015	146,464	3.21%	39,264
Domestic use	572,833	580,896	588,829	598,935	609,066	618,755	629,195	637,871	646,136	654,258	660,746	668,341	1.45%	95,507
Total trade	38,994	39,614	39,795	40,462	41,236	41,505	42,309	42,995	43,652	44,300	44,971	45,437	1.44%	6,443
						(percent)							(2012-23)	(2012-23)
Stocks-to-use ratio	23.02	22.46	23.07	23.86	24.61	25.30	26.02	26.52	27.06	27.46	27.62	28.06	2.17%	5

Table 3. United States rice supply and utilization, 2012-2023.

	12/13	13/14	14/15	15/16	16/17	17/18	18/19	19/20	20/21	21/22	22/23	23/24	Percent growth	Total qty change
	(thousand hectares)												(2012-23)	(2012-23)
Area harvested	1,084	999	1,060	1,072	1,082	1,091	1,100	1,118	1,125	1,113	1,106	1,100	0.62%	16
	(metric tons/hectare)												(2012-23)	(2012-23)
Yield	5.85	6.02	6.05	6.08	6.11	6.13	6.15	6.17	6.20	6.23	6.25	6.28	0.51%	0
	(thousand metric tons)												(2012-23)	(2012-23)
Production	6,336	6,013	6,415	6,517	6,608	6,691	6,769	6,903	6,972	6,934	6,917	6,909	1.14%	573
Beginning stocks	1,303	1,156	923	1,025	1,140	1,230	1,220	1,242	1,272	1,309	1,294	1,215	1.42%	-88
Domestic supply	7,639	7,169	7,338	7,542	7,749	7,921	7,989	8,145	8,244	8,242	8,211	8,125	1.17%	486
Consumption	3,752	3,843	4,008	4,104	4,182	4,305	4,416	4,540	4,569	4,576	4,680	4,599	2.03%	847
Ending Stocks	1,156	923	1,025	1,140	1,230	1,220	1,242	1,272	1,309	1,294	1,215	1,198	1.87%	42
Domestic use	4,908	4,766	5,033	5,244	5,412	5,525	5,659	5,812	5,878	5,871	5,895	5,797	1.99%	889
Net trade	2,731	2,407	2,305	2,298	2,337	2,395	2,330	2,334	2,366	2,372	2,316	2,328	-0.62%	-403
	(U.S. dollars/cwt)												(2012-23)	(2012-23)
U.S. rice farm prices														
Season average farm price	14.90	15.44	14.42	14.31	14.21	13.63	13.69	13.56	13.52	13.48	13.44	13.47	-1.13%	-1.43
Long-grain average farm price	14.40	14.92	13.92	13.73	13.52	12.75	12.81	12.67	12.62	12.51	12.43	12.42	-1.61%	-1.98
Medium-grain average farm price	16.70	16.63	15.57	15.65	15.79	15.62	15.71	15.61	15.61	15.69	15.71	15.78	-0.39%	-0.92

Table 4. Rice per capita use by country, 2012-2023.

	12/13	13/14	14/15	15/16	16/17	17/18	18/19	19/20	20/21	21/22	22/23	23/24	Percent growth	Total qty change
	(kilograms/year)												(2012-23)	(2012-23)
Argentina	10.3	10.4	10.4	10.4	10.4	10.4	10.4	10.4	10.4	10.4	10.4	10.4	-0.01%	0.01
Australia	17.4	15.5	14.9	14.8	14.6	14.5	14.5	14.3	14.2	14.1	14.1	14.2	-1.26%	-3.11
Bangladesh	222.9	221.4	222.2	224.4	225.2	226.8	228.2	228.2	228.1	228.2	228.4	228.8	0.31%	6.00
Brazil	39.5	39.9	39.1	39.0	39.1	39.0	39.1	39.1	39.1	39.2	39.1	39.2	-0.08%	-0.31
Brunei Darussalam	111.6	115.1	116.2	117.5	117.7	118.8	121.2	121.4	122.8	123.6	124.9	125.8	0.99%	14.17
Cambodia	243.2	251.5	251.7	252.0	252.3	252.8	253.0	253.2	254.2	255.2	256.1	256.9	0.32%	13.71
Cameroon	32.1	34.0	33.1	33.5	33.4	33.8	33.7	34.1	35.0	34.7	34.8	33.9	0.49%	1.71
Canada	10.1	10.2	10.6	11.7	12.0	12.2	12.4	12.6	12.7	12.8	12.9	13.1	2.46%	3.06
People's Republic of China	97.8	98.9	98.3	98.0	97.5	97.1	96.7	96.5	96.0	95.9	95.6	95.4	-0.31%	-2.39
Colombia	32.6	32.0	32.2	32.9	34.6	35.2	35.7	35.5	35.1	34.8	34.7	34.5	0.82%	1.93
Cote d'Ivoire	89.4	92.1	93.0	91.5	91.2	91.9	93.1	92.9	93.4	95.2	94.5	95.2	0.44%	5.79
Egypt	48.3	49.8	48.8	48.4	48.6	48.5	48.5	48.1	48.1	47.7	47.3	47.9	-0.27%	-0.41
European Union-27	6.6	6.7	6.7	6.7	6.7	6.7	6.7	6.8	6.8	6.8	6.8	6.8	0.29%	0.25
Ghana	35.5	35.7	36.4	37.2	38.0	39.1	41.4	42.5	43.6	44.5	45.3	46.4	2.73%	10.96
Guinea	131.9	132.1	132.9	131.6	132.2	132.7	134.0	134.7	135.8	137.0	136.8	137.3	0.42%	5.42
China - Hong Kong	59.5	60.8	61.2	61.2	61.6	61.8	62.1	62.3	62.6	62.8	63.0	64.4	0.54%	4.92
India	75.6	75.9	76.2	76.6	77.0	77.5	77.7	78.1	78.5	78.8	79.1	79.3	0.46%	3.72
Indonesia	158.8	160.1	159.4	159.5	158.8	158.5	158.7	158.4	158.2	157.9	157.7	157.3	-0.12%	-1.48
Iran	43.2	43.6	43.8	43.6	44.2	44.2	44.5	44.8	44.6	44.9	45.1	45.0	0.38%	1.77
Iraq	44.2	44.7	44.2	44.8	45.3	45.9	46.2	46.6	46.7	46.9	47.1	47.2	0.66%	2.93
Japan	64.7	64.1	63.7	62.8	62.1	61.8	61.6	61.2	60.9	60.8	60.6	60.1	-0.64%	-4.53
Kenya	10.7	11.3	11.4	12.5	12.7	13.2	14.3	15.0	15.7	16.1	16.3	16.5	4.39%	5.87
Lao PDR	225.7	226.5	226.9	227.2	228.5	228.8	229.4	228.9	228.8	230.0	229.9	231.5	0.19%	5.78
Liberia	104.4	97.1	100.0	100.8	104.7	106.3	109.0	109.5	110.8	112.1	111.5	113.6	1.27%	9.18
Malaysia	93.2	94.2	94.2	93.8	94.5	94.6	94.7	95.1	95.3	95.6	95.7	95.8	0.23%	2.60
Mali	96.4	100.1	101.4	101.2	103.0	104.1	106.3	107.6	108.6	109.3	110.6	111.7	1.25%	15.25
Mexico	6.9	7.1	7.2	7.3	7.3	7.4	7.5	7.6	7.6	7.7	7.7	7.7	1.00%	0.78
Mozambique	28.1	28.9	26.7	27.6	27.4	27.5	28.5	28.6	29.7	30.5	31.7	32.0	1.32%	3.99

continued

Table 4. Continued.

	12/13	13/14	14/15	15/16	16/17	17/18	18/19	19/20	20/21	21/22	22/23	23/24	Percent growth	Total qty change
	--(kilograms/year)--												(2012-23)	(2012-23)
Myanmar (Burma)	165.6	165.4	164.1	163.0	161.7	161.4	162.1	162.3	162.9	162.6	161.7	162.7	-0.16%	-2.92
Nigeria	32.0	34.9	34.1	34.2	34.0	33.9	34.4	34.5	34.8	35.0	35.1	35.1	0.50%	3.14
Pakistan	13.9	14.4	14.8	15.0	15.2	15.2	15.3	15.4	15.3	15.4	15.4	15.4	0.75%	1.47
Philippines	132.9	130.9	130.7	129.5	129.0	128.0	127.6	127.0	126.7	126.0	125.5	124.9	-0.52%	-7.97
Saudi Arabia	43.3	43.9	44.5	45.2	45.9	46.3	46.6	47.0	47.2	47.5	47.7	48.0	0.93%	4.68
Senegal	113.2	111.9	111.1	111.6	112.3	112.8	113.2	113.5	113.8	114.0	114.2	114.4	0.22%	1.18
Sierra Leone	183.0	184.0	185.8	187.4	190.2	191.3	193.7	196.1	198.4	201.1	202.5	204.7	1.07%	21.63
Singapore	66.0	66.8	65.9	66.3	65.5	64.8	64.0	63.2	62.4	61.5	60.7	61.9	-0.86%	-4.08
South Africa	17.9	18.4	18.1	18.2	18.1	18.2	18.4	18.4	18.5	18.9	18.7	19.2	0.47%	1.29
South Korea	92.3	92.1	90.9	91.2	90.4	90.1	89.4	88.7	87.9	87.7	87.5	86.7	-0.58%	-5.61
Taiwan	55.3	55.4	54.9	54.4	54.0	53.2	52.5	52.2	51.9	51.6	51.3	51.0	-0.82%	-4.27
Tanzania	24.3	24.5	25.4	25.8	25.9	26.2	26.8	27.0	27.4	28.0	28.3	28.5	1.47%	4.25
Thailand	158.7	159.7	158.4	158.0	157.3	157.1	157.2	157.1	157.3	157.6	157.6	157.8	-0.09%	-0.88
Turkey	10.3	10.4	10.4	10.4	10.3	10.4	10.5	10.2	10.1	10.2	10.2	10.1	-0.22%	-0.16
United States	11.9	12.1	12.5	12.7	12.9	13.2	13.4	13.7	13.7	13.6	13.8	13.4	1.26%	1.52
Uruguay	25.0	26.7	25.3	25.5	24.7	24.4	24.3	24.0	23.8	23.4	22.8	22.2	-1.29%	-2.79
Vietnam	221.4	225.4	224.2	222.0	222.4	221.5	221.9	222.1	221.1	221.0	221.3	221.5	-0.10%	0.09
Rest of World	22.2	22.6	22.5	22.6	22.8	23.0	23.1	23.3	23.4	23.6	38.0	23.8	2.13%	1.59
World	65.5	66.0	65.8	65.8	65.8	65.7	65.8	65.8	65.7	65.7	65.7	65.6	-0.01%	0.12

Table 5. Rice yield in metric tons/hectare by country, 2012-2023.

	12/13	13/14	14/15	15/16	16/17	17/18	18/19	19/20	20/21	21/22	22/23	23/24	Percent growth	Total qty change
	----------	----------	----------	----------	----------	(thousand	metric tons)	----------	----------	----------	----------	----------	(2012-23)	(2012-23)
Argentina	4.35	4.20	4.34	4.49	4.56	4.63	4.67	4.71	4.76	4.80	4.85	4.89	1.30%	0.54
Australia	7.37	7.07	7.05	7.04	7.03	7.04	7.05	7.05	7.07	7.10	7.11	7.11	-0.09%	-0.26
Bangladesh	2.90	2.92	2.92	2.92	2.94	2.97	3.00	3.02	3.05	3.08	3.09	3.12	0.69%	0.21
Brazil	3.34	3.39	3.40	3.42	3.43	3.46	3.48	3.49	3.50	3.51	3.52	3.53	0.46%	0.19
Brunei Darussalam	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.00%	0.00
Cambodia	1.56	1.65	1.70	1.78	1.87	1.91	2.00	2.06	2.12	2.17	2.23	2.27	3.47%	0.72
Cameroon	0.65	0.90	0.97	1.07	1.08	1.08	1.09	1.08	1.08	1.09	1.09	1.09	2.92%	0.44
Canada	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00%	0.00
People's Republic of China	4.74	4.67	4.80	4.85	4.88	4.92	4.95	4.99	5.01	5.04	5.07	5.10	0.74%	0.36
Colombia	3.17	2.99	3.00	3.01	3.02	3.04	3.05	3.07	3.08	3.10	3.11	3.12	0.20%	-0.05
Egypt	6.07	6.48	6.69	6.77	6.80	6.83	6.86	6.88	6.94	7.00	7.06	7.12	1.06%	1.05
European Union-27	4.63	4.62	4.67	4.74	4.81	4.88	4.94	5.01	5.08	5.14	5.21	5.25	1.27%	0.62
Ghana	1.52	1.69	1.72	1.75	1.80	1.85	1.89	1.94	1.96	2.00	2.04	2.08	2.48%	0.56
Guinea	1.27	1.27	1.34	1.40	1.46	1.50	1.54	1.58	1.62	1.65	1.69	1.72	2.99%	0.46
China - Hong Kong	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00%	0.00
India	2.46	2.37	2.45	2.48	2.51	2.54	2.58	2.60	2.63	2.66	2.67	2.74	1.13%	0.27
Indonesia	3.00	3.10	3.14	3.17	3.21	3.26	3.29	3.31	3.34	3.36	3.37	3.39	1.04%	0.40
Iran	2.77	2.81	2.83	2.86	2.88	2.91	2.93	2.96	2.98	3.01	3.03	3.06	0.88%	0.29
Iraq	2.13	2.17	2.17	2.19	2.20	2.22	2.23	2.24	2.25	2.27	2.28	2.29	0.61%	0.16
Cote d'Ivoire	1.20	1.23	1.33	1.43	1.47	1.51	1.55	1.59	1.63	1.67	1.71	1.75	3.41%	0.54
Japan	4.91	4.80	4.81	4.81	4.80	4.81	4.80	4.80	4.80	4.80	4.79	4.79	-0.11%	-0.12
Kenya	1.83	1.80	1.82	1.83	1.84	1.84	1.85	1.86	1.86	1.87	1.87	1.87	0.31%	0.04
Lao PDR	1.72	1.77	1.80	1.83	1.87	1.93	1.98	2.02	2.07	2.11	2.15	2.17	2.24%	0.46
Liberia	0.72	0.78	0.79	0.80	0.80	0.81	0.82	0.83	0.84	0.85	0.85	0.86	1.29%	0.14
Malaysia	2.51	2.58	2.58	2.59	2.62	2.64	2.66	2.69	2.73	2.75	2.79	2.82	0.99%	0.31
Mali	2.18	2.19	2.23	2.28	2.35	2.41	2.47	2.54	2.59	2.65	2.71	2.77	2.33%	0.58
Mexico	3.74	3.74	3.71	3.77	3.81	3.78	3.73	3.75	3.73	3.73	3.77	3.79	0.05%	0.05
Mozambique	0.93	0.94	0.95	0.97	0.99	1.01	1.03	1.04	1.05	1.07	1.09	1.11	1.67%	0.18

continued

Table 5. Continued.

	12/13	13/14	14/15	15/16	16/17	17/18	18/19	19/20	20/21	21/22	22/23	23/24	Percent growth	Total qty change
	----------(thousand metric tons)----------												(2012-23)	(2012-23)
Myanmar (Burma)	1.68	1.69	1.71	1.73	1.74	1.76	1.78	1.80	1.81	1.83	1.85	1.87	0.97%	0.19
Nigeria	1.19	1.16	1.22	1.24	1.27	1.31	1.34	1.37	1.41	1.44	1.48	1.51	2.44%	0.33
Pakistan	2.42	2.34	2.36	2.36	2.36	2.36	2.37	2.37	2.37	2.37	2.38	2.39	0.04%	-0.03
Philippines	2.43	2.47	2.48	2.51	2.56	2.62	2.67	2.71	2.77	2.83	2.88	2.93	1.76%	0.50
Saudi Arabia	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00%	0.00
Senegal	3.19	3.38	3.57	3.76	3.97	4.19	4.42	4.62	4.82	5.03	5.25	5.43	5.01%	2.24
Sierra Leone	1.34	1.25	1.28	1.32	1.37	1.41	1.45	1.50	1.54	1.59	1.64	1.69	2.68%	0.35
Singapore	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00%	0.00
South Africa	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00%	0.00
South Korea	4.72	5.02	5.02	5.03	5.04	5.05	5.05	5.05	5.05	5.05	5.05	5.05	0.31%	0.33
Taiwan	4.17	4.14	4.14	4.14	4.14	4.14	4.15	4.15	4.16	4.18	4.21	4.24	0.16%	0.07
Tanzania	1.04	1.04	1.05	1.07	1.09	1.11	1.13	1.15	1.17	1.19	1.21	1.23	1.64%	0.19
Thailand	1.86	1.88	1.88	1.90	1.92	1.92	1.94	1.96	1.97	1.97	1.97	1.98	0.58%	0.12
Turkey	4.69	4.89	4.93	4.99	5.05	5.11	5.17	5.23	5.29	5.34	5.40	5.46	1.24%	0.77
United States	5.85	6.02	6.05	6.08	6.11	6.13	6.15	6.17	6.20	6.23	6.25	6.28	0.51%	0.43
Uruguay	5.50	5.63	5.74	5.79	5.87	5.91	5.96	6.00	6.05	6.09	6.17	6.25	1.03%	0.75
Vietnam	3.52	3.54	3.55	3.58	3.60	3.63	3.66	3.69	3.72	3.75	3.78	3.81	0.74%	0.28
Rest of World	2.24	2.30	2.33	2.34	2.36	2.38	2.40	2.42	2.45	2.47	2.50	2.52	0.97%	0.28
World	2.98	2.95	3.00	3.03	3.06	3.08	3.11	3.13	3.16	3.18	3.20	3.23	0.80%	0.25

ECONOMICS

Measuring Input Use Efficiency in Rice Production Using Data from the Rice Research Verification Program

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ABSTRACT

Large expenses associated with rice production and dependence on energy related inputs like irrigation water, fuel, and fertilizer in particular compel rice producers to use inputs efficiently. This study uses data envelopment analysis (DEA) to calculate non-radial technical efficiency scores for rice fields and inputs used on 98 rice fields enrolled in the University of Arkansas System Division of Agriculture Rice Research Verification Program (RRVP) for the period 2005 to 2013. The average non-radial technical efficiency score was 0.724, indicating an average technical inefficiency of 0.276 (1 – 0.724) for the 98 RRVP fields. Some inputs were found to contribute more to overall technical inefficiency than others. Herbicides, nitrogen, field size, and irrigation water contributed the least to overall field technical inefficiency, while fungicides, insecticides, other soil amendments, potassium, and phosphorus contributed most to overall field technical inefficiency.

INTRODUCTION

Agricultural production expenses have trended upward since 2001 as a result of higher energy costs (Trostle, 2008; Beckman et al., 2013). Fuel and fertilizer prices increased significantly due to increased energy demand in developing countries such as China (Trostle, 2008). Rice is a high input cost crop relative to other crops grown in Arkansas. Because of the large expenses associated with rice production and the large dependence on energy related inputs like fertilizer, and irrigation water in particular, rice producers in Arkansas and the U.S. seek production systems that utilize inputs efficiently.

This analysis quantifies technical efficiency of rice production at the field level using non-radial analysis. Technical efficiency measures the ability of a field to produce a given level of output using the minimum feasible amounts of inputs. Non-radial technical efficiency allows the user to calculate efficiency scores not only for the field itself but also for each production input used on the field. Data for this study are obtained from 98 fields enrolled in the University of Arkansas System Division of Agriculture Rice Research Verification Program (RRVP) for the period 2005 through 2013.

PROCEDURES

This study uses data envelopment analysis (DEA) to calculate non-radial technical efficiency scores for rice fields and inputs used on rice fields enrolled in the RRVP. Data envelopment analysis is a linear programming (LP) approach for measuring relative efficiency among a set of decision making units (rice fields in this case) and allows for incorporation of multiple inputs and outputs. The non-radial technical efficiency for a given field and for each input used on the field is found by solfing the following LP minimization problem used by Fernandez-Cornejo (1994) and Piot-Lepetit et al. (1997):

$$NRTE_n = \min_{\lambda_i \theta_{nj}} \sum_{j=1}^{J} \frac{\theta_{nj}}{J}$$

Subject to:

$$\sum_{i=1}^{I} \lambda_i x_{ij} - \theta_{nj} x_{nj} \leq 0$$

$$\sum_{i=1}^{I} \lambda_i y_{ik} - y_{nk} \geq 0$$

$$\sum_{i=1}^{I} \lambda_i = 1$$

$$\lambda_i \geq 0$$

where $NRTE_n$ = the overall non-radial technical efficiency for field n, i = 1 to I fields; j = 1 to J inputs; k = 1 to K outputs; λ_i = the nonnegative weights for I fields; x_{ij} = the amount of input j utilized on field i; x_{nj} = the amount of input j used on field n; y_{ik} = the amount of output k produced on field i; y_{nk} = the amount of output k produced on field n; and Θ_{nj} = the non-radial technical efficiency for input j on field n. $NRTE_n$ takes on a value ≤ 1, with a value of 1 indicating an overall non-radial technically efficient field and a value less than 1 indicating an overall non-radial technically inefficient field, with the level of technical inefficiency equal to $1 - NRTE_n$.

The non-radial efficiencies for each input (Θ_{nj}) can take on values of less than, equal to, or greater than 1 depending on the relationship between input j on field n (x_{nj}) and the weighted sum of input j across all fields.

$$\left(\sum_{i=1}^{I} \lambda_i x_{ij}\right)$$

The weighted sum of input *j* across all fields represents the minimum amount of input *j* required to achieve the desired level of output on the field as determined by the LP model. Since Θ_{nj} is calculated as a ratio of

$$\sum_{i=1}^{I} \lambda_i x_{ij}$$

and x_{nj}, Θ_{nj} will be ≤1 if

$$x_{nj} \geq \sum_{i=1}^{I} \lambda_i x_{ij}$$

In this instance, the input is either used efficiently ($\Theta_{nj} = 1$) or overused ($\Theta_{nj} < 1$), with the amount of input overuse equal to $1 - \Theta_{nj}$. If however

$$x_{nj} < \sum_{i=1}^{I} \lambda_i x_{ij}$$

then Θ_{nj} will be greater than 1, implying the input is being underused, with the amount of input underuse equal to $\Theta_{nj} - 1$.

Data for the analysis were obtained from 98 rice fields enrolled in 2005 through 2013 in which water usage was measured for the growing season using flow meters (Table 1). Inputs for the DEA analysis include field size (acres); irrigation water (acre inches); diesel fuel (gallons); nitrogen, phosphorus, and potassium (lb); seed (lb); costs of other soil amendments ($); herbicide, insecticide, and fungicide costs ($); and custom charges ($). Output for the DEA analysis is measured as the value of rice production (rice yield × milling yield adjusted rice price × field size). Inputs such as fungicides, insecticides and other soil amendments are used on an "as needed" basis and are not used on every field. Thus the number of inputs per field varies across the 98 RRVP fields from a low of 7 to the maximum of 12 (Table 1). All economic data (prices and costs) are converted to 2012 dollars using the Producer Price Index.

RESULTS AND DISCUSSION

Non-radial technical efficiency (NRTE) score summary statistics by field and by input are presented in Table 2. Overall NRTE scores are calculated as the sum of all non-radial input efficiency scores for each field divided by the number of inputs used on the field. A NRTE score of one represents full technical efficiency for a particular field, while a NRTE score less than one implies technical inefficiency for the field equaling 1 – NRTE. Twenty-three of the 98 RRVP fields exhibited full non-radial technical efficiency (NRTE score = 1). The remaining 75 fields had NRTE scores less than 1, indicating that 86.7% of the 98 RRVP fields exhibited technical inefficiency. The 98 RRVP fields averaged a NRTE score of 0.724, indicating existence of average technical inefficiency of 0.276 (1 – 0.724) across the 98 RRVP fields.

Average input NRTE scores are reported in Table 2. Input technical efficiency scores less than one for a particular input indicate overuse of that input on the field, while input technical efficiency scores greater than one indicate underuse of that input on the field. Herbicides is the only input with a mean efficiency score greater than 1 (1.057), implying herbicides on average are underused across the 98 RRVP fields. All other inputs listed in Table 2 are less than one, implying they are overused on average across the 98 RRVP fields. Herbicides, nitrogen, field size, and irrigation water have the largest mean technical efficiency scores, (1.057, 0.912, 0.868, and 0.775, respectively), implying these inputs are used more efficiently relative to the other inputs listed in Table 2. Inputs with the lowest mean technical efficiency scores are fungicides (0.106), insecticides (0.133), other soil amendments (0.210), potassium (0.183), and phosphorus (0.390). These latter inputs are applied on an "as needed" basis. For example, insecticides and fungicides may or may not be applied on a particular field unless insect or disease pressures reach a certain threshold level to warrant their necessity.

Input overuse summary statistics are presented in Table 3. Input overuse for a particular input is calculated when the NRTE score for the input is less than one (input overuse equals 1 minus the input's NRTE score). Input overuse is zero for inputs with NRTE scores greater than or equal to one. The input overuse scores reported in Table 3 represent the percent overuse associated with each input across the 98 RRVP fields. For example, the irrigation water input overuse score of 0.279 in Table 3 means that irrigation water was overused on average by 27.9% across the 98 RRVP fields.

Average input overuse scores are larger for some inputs relative to others. Herbicides, nitrogen, and field size have the smallest average input overuse scores across the 98 RRVP fields (0.109, 0.147, and 0.147, respectively), while other soil amendments, seed, potassium, and fungicides have the largest average input overuse scores across the 98 RRVP fields (0.450, 0.349, 0.337, and 0.302, respectively). Table 3 also presents the number and percent of fields overusing each specific input. Over 50% of the 98 RRVP fields overuse land area, irrigation water, nitrogen, phosphorus, machinery diesel, seed, other soil amendments, and custom application inputs. Potassium, herbicides, insecticides, and fungicides are overused on less than half the 98 RRVP fields. The lower percentage of fields over applying these inputs may be more a reflection of the fact that application of these types of inputs is zero (with the exception of "herbicides") for many RRVP fields in the analysis.

Input underuse summary statistics are presented in Table 4. Input underuse for a particular input is calculated when the NRTE score for the input is greater than one (input underuse equals the input's NRTE score minus 1). Input underuse is zero for inputs with NRTE scores less than or equal to one. Average input underuse across the 98 RRVP fields is small for all inputs listed in Table 2 with the exception of herbicides. Average herbicide underuse across all 98 RRVP fields is 0.166. For all other inputs, input underuse scores range from 0 for potassium and fungicides to 0.059 for nitrogen.

Input underuse occurs on a smaller proportion of fields relative to input overuse. Most RRVP fields underused herbicides (40%), followed by nitrogen (21%) and irrigation water (17%).

SIGNIFICANCE OF FINDINGS

The results reveal technical inefficiency exists for most fields enrolled in the RRVP. However, some inputs play more of a role in overall technical inefficiency on rice fields than others. Herbicides, nitrogen, field size, and irrigation water contribute the least to overall field technical inefficiency, while fungicides, insecticides, other soil amendments, potassium, and phosphorus contribute most to overall field technical inefficiency. These latter inputs are applied when needed, and are not applied to all 98 fields in the analysis. These results imply that fields with an inherent disease history or fields requiring chicken litter or other soil amendments to enhance soil productivity will have a distinct efficiency disadvantage relative to fields without such deficiencies.

Inputs can be both overused or underused on rice fields. Most fields exhibited both overuse and underuse of inputs. However, the incidence of input overuse was greater than that for input underuse across fields, implying input overuse is more of a concern relative to input underuse. Many inputs like irrigation water, nitrogen, and diesel were overused on over half of the fields evaluated in the study. These results point to a need for greater input efficiency in rice production. More analysis needs to be conducted to determine the factors affecting input overuse in rice production.

ACKNOWLEDGMENTS

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Table 1. Output and inputs summary statistics used in the data envelopment analysis (DEA).

Variable	Mean[a]	SD[b]	CV[c]	Minimum	Median	Maximum
Output[d]						
Rice production value ($)[e]	55,246	34,966	63	14,743	46,073	228,122
Inputs						
Field size (acres)	51	26	51	12	45	146
Irrigation water (acre inches)	1,541	851	55	288	1,329	4,453
Nitrogen (lb)[f]	8,606	4,592	53	1,932	7,205	27,472
Phosphorus (lb)[f]	1,587	1,682	106	0	1,310	6,845
Potassium (lb)[f]	1,966	2,538	129	0	1,236	12,611
Machinery diesel (gallons)	456	270	59	56	392	1,515
Seed (lb)	3,567	2,593	73	644	2,840	11,560
Other soil amendments ($)[g]	595	1,396	235	0	186	9,420
Herbicides ($)	3,388	2,117	62	397	2,819	13,298
Insecticides ($)	206	385	187	0	0	2,259
Fungicides ($)	477	703	147	0	0	2,912
Custom charges ($)	2,479	1,619	65	526	2,087	9,577
Number of inputs	10	1	13	7	10	12

[a] Summary statistics calculated from 98 fields enrolled in the University of Arkansas Rice Research Verification Program for the period 2005 to 2013 with water usage measured by flow meter.

[b] SD = standard deviation.

[c] CV = coefficient of variation.

[d] Rice values and input costs are adjusted to 2012 dollars using the Producer Price Index.

[e] Rice production value = field yield (bu/acre) * rice price adjusted for milling quality ($/bu) * field size (acres)

[f] Input levels for nitrogen, phosphorus, and potassium are in elemental levels.

[g] Other soil amendments include chicken litter, zinc, and/or urease inhibitors.

Table 2. Non-Radial Technical Efficiency (NRTE) Score Summary Statistics of 98 University of Arkansas Rice Research Verification Program Fields.

Efficience score	Mean	SD[a]	CV[b]	Minimum	Median	Maximum
NRTE[c]	0.724	0.222	31	0.287	0.731	1.000
Field size	0.868	0.180	21	0.468	0.890	1.255
Irrigation water	0.775	0.373	48	0.134	0.779	2.184
Nitrogen	0.912	0.273	30	0.392	0.945	2.077
Phosphorus	0.390	0.416	107	0.000	0.339	1.926
Potassium	0.183	0.312	171	0.000	0.000	1.000
Machinery diesel	0.762	0.314	41	0.165	0.781	1.590
Seed	0.667	0.350	53	0.091	0.725	1.691
Other soil amendments	0.210	0.371	177	0.000	0.000	1.530
Herbicides	1.057	0.400	38	0.363	1.000	2.399
Insecticides	0.133	0.323	243	0.000	0.000	1.096
Fungicides	0.106	0.278	263	0.000	0.000	1.000
Custom applications	0.766	0.316	41	0.236	0.722	1.971

[a] SD = standard deviation.

[b] CV = coefficient of variation.

[c] NRTE = Non-Radial Technical Efficiency.

Table 3. Input overuse summary statistics of 98 University of Arkansas Rice Research Verification Program Fields.

Input	Mean	SD[a]	CV[b]	Minimum	Median	Maximum	N[c]	Percent
Field size	0.148	0.160	109	0.000	0.110	0.532	61	62%
Irrigation water	0.279	0.283	101	0.000	0.221	0.866	58	59%
Nitrogen	0.147	0.174	118	0.000	0.055	0.608	54	55%
Phosphorus	0.287	0.341	119	0.000	0.078	1.000	50	51%
Potassium	0.337	0.415	123	0.000	0.000	1.000	44	45%
Machinery diesel	0.271	0.265	98	0.000	0.219	0.835	62	63%
Seed	0.349	0.325	93	0.000	0.275	0.909	66	67%
Other soil amendments	0.450	0.458	102	0.000	0.414	1.000	48	49%
Herbicides	0.109	0.184	169	0.000	0.000	0.637	36	37%
Insecticides	0.256	0.423	165	0.000	0.000	1.000	27	28%
Fungicides	0.302	0.442	146	0.000	0.000	1.000	32	33%
Custom applications	0.269	0.243	90	0.000	0.278	0.764	65	66%

[a] SD = standard deviation.

[b] CV = coefficient of variation.

[c] N = number of fields.

Table 4. Input Underuse summary statistics of 98 University of Arkansas Rice Research Verification Program Fields.

Input	Mean	SD[a]	CV[b]	Minimum	Median	Maximum	N[c]	Percent
Field size	0.016	0.046	297	0.000	0.000	0.255	14	14%
Irrigation water	0.054	0.170	316	0.000	0.000	1.184	17	17%
Nitrogen	0.059	0.164	278	0.000	0.000	1.077	21	21%
Phosphorus	0.014	0.099	731	0.000	0.000	0.926	3	3%
Potassium	0.000	0.000	0	0.000	0.000	0.000	0	0%
Machinery diesel	0.033	0.104	317	0.000	0.000	0.590	13	13%
Seed	0.016	0.079	504	0.000	0.000	0.691	9	9%
Other soil amendments	0.007	0.056	793	0.000	0.000	0.530	2	2%
Herbicides	0.166	0.300	180	0.000	0.000	1.399	39	40%
Insecticides	0.001	0.010	990	0.000	0.000	0.096	1	1%
Fungicides	0.000	0.000	0	0.000	0.000	0.000	0	0%
Custom applications	0.036	0.145	406	0.000	0.000	0.971	10	10%

[a] SD = standard deviation.

[b] CV = coefficient of variation.

[c] N = number of fields with underuse of specified input.

ECONOMICS

Impacts of Field Characteristic on Irrigation Water Overuse in Rice Production

K.B. Watkins, C.G. Henry, R. Mazzanti, L.A. Schmidt, and J.T. Hardke

ABSTRACT

Water is a key input in rice production but is becoming increasingly more limiting in many parts of eastern Arkansas due to extensive pumping of groundwater. An earlier B.R. Wells study was conducted to evaluate the technical efficiency of input application in rice production using data from 98 fields enrolled in the University of Arkansas, Rice Research Verification Program (Watkins et al., 2014a). Results of that study indicated that irrigation water was overused on 59% of the fields evaluated with average irrigation water overuse estimated at 27.9% across all fields. The present study uses data from the former study to investigate the impacts of specific field characteristics on irrigation water overuse using Tobit regression analysis. The results of the Tobit analysis indicate that irrigation water overuse is reduced on fields without levees, fields receiving irrigation water from surface water rather than groundwater sources, and fields using multiple inlet irrigation.

INTRODUCTION

Irrigation water is a key production input in Arkansas row crop production. Extensive pumping of groundwater has caused a steady depletion of the alluvial aquifer in many areas of eastern Arkansas (Czarnecki, 2010; Gillip and Czarnecki, 2009; Schrader, 2010). Several counties have been either partially or totally designated as critical groundwater areas because of significant groundwater declines resulting from intensive irrigation (Czarnecki, 2010; Gillip and Czarnecki, 2009). Producers in areas affected by limited water availability must adapt to shrinking water supplies either by adopting management strategies/technologies that conserve water resources or by converting to less profitable and less reliable non-irrigated crop production.

Rice has the largest water requirement of any row crop grown in the state, averaging 30 acre-inches of irrigation water in a normal growing season (Hardke and Wilson, 2013). An earlier B.R. Wells study (Watkins et al., 2014a) evaluated technical efficiencies for various rice production inputs using data from 98 fields enrolled in the University of Arkansas Division of Agriculture, Rice Research Verification Program (RRVP). The former study found irrigation water was overused on 59% of the 98 fields evaluated with average irrigation water overuse estimated at 27.9%. The present study seeks to evaluate the impacts of field characteristics on water overuse using Tobit regression analysis.

PROCEDURES

Irrigation water overuse per field takes on either a value of 0 (no irrigation water overuse) or a value greater than 0, but less than 1 (positive irrigation water overuse). As mentioned earlier, 59 of the 98 RRVP fields evaluated in the former B.R. Wells study had positive irrigation water overuse scores, while the remaining 41 fields evaluated did not (Watkins et al., 2014a). This study uses a two-limit Tobit regression model to evaluate the impacts of field characteristic variables on irrigation water overuse. A two-limit Tobit regression model was used because the dependent variable in this study (water overuse scores) is bounded between 0 and 1. The Tobit model is expressed as follows:

$$y_i^* = \beta_0 + \sum^{M} \beta_m x_{im} + \varepsilon_i, \quad \varepsilon_i \sim N\left(0, \sigma^2\right)$$

where y_i* = a latent variable representing the water overuse score for field *i*; β_0 and β_m are unknown parameters to estimate; x_{im} = 1 to *M* explanatory field characteristic variables associated with field *i*; and ε_i = an error term that is independently and normally distributed with zero mean and constant variance σ^2 (Maddala, 1983).

The explanatory variables used in the Tobit regression are listed in Table 1. Explanatory variables include field size, the year the field was enrolled in the program (2005 to 2013), the field location (Northeast Region, Central East Region, Other Locations), whether or not the field used hybrid or non-hybrid, pure-line varieties, the soil texture of the field (silt loam or clay), the crop grown the previous year (soybean or some other crop), whether or not the field had levees, whether or not the field used surface water or groundwater from wells, whether or not the field used electric or diesel power as the irrigation power source, and whether or not the field used multiple inlet irrigation. Field size is measured in acres. All other explanatory variables are zero-one dummy variables (1 if field was enrolled in 2012, 0 otherwise; 1 if the field was planted to a 'hybrid' rice variety, 0 otherwise, et cetera). For a more detailed explanation of field characteristic variables used in this study, see Watkins et al. (2014b) .

RESULTS AND DISCUSSION

Tobit analysis results of field characteristic impacts on irrigation water overuse scores are presented in Table 2. Significantly negative coefficients for water overuse would indicate the field characteristic reduces water overuse. The field size coefficient and the locational coefficients were not significant. Coefficients for the year in which the field was enrolled in the RRVP were also for the most part insignificant, with the exception of 2009. The coefficient for 2009 was significantly negative at the 5% level, indicating irrigation water overuse was reduced on fields enrolled into the program in 2009. The year 2009 was a relatively wet year with timely rains during the growing season. Thus, the negative and significant 2009 coefficient for water overuse would be expected, as less irrigation water would have been needed that year.

The coefficient for hybrid was not significant, nor were the coefficients for soybean or electric power. However, the coefficient for silt loam was significant and positive at the 1% level, indicating rice planted to silt loam fields increases overuse of irrigation water. This result is likely due to the terrain of most fields with silt loam soils. Fields with silt loam soils are found in higher concentrations in areas of eastern Arkansas where the terrain is more rolling and where water management across fields is more difficult.

The levee coefficient is positive and significant at the 5% level, indicating fields with levees increase water overuse as opposed to fields without levees. Fields without levees in this analysis are primarily zero-grade fields (Non-levee fields include 14 zero grade fields; 4 furrow-irrigated fields). Zero grade fields use significantly less irrigation water and fuel than fields with levees. The coefficient for surface water is negative and significant at the 5% level, indicating fields supplied by surface water have less water overuse relative to fields supplied by groundwater via wells. This result is likely due to better irrigation water management on the part of rice producers on fields supplied with surface water. Areas using surface water are often areas for which groundwater supplies are highly variable, dwindling, or non-existent. Many rice producers in Arkansas have dealt with decreasing groundwater supplies by constructing on-farm reservoirs and tailwater recovery pits to capture precipitation and field runoff. These producers have developed the infrastructure necessary to capture and reuse water and thus may exhibit a mindset for greater water management. The coefficients for multiple inlet is negative and significant at the 5% level, indicating that rice fields with multiple inlet irrigation reduce water overuse.

SIGNIFICANCE OF FINDINGS

The Tobit analysis provides evidence that water efficiency may be improved by capital investments made either to level land to achieve more efficient water delivery across the field (zero grade) or to build reservoirs and tailwater recovery pits to capture precipitation and field runoff. The Tobit analysis also provided evidence that greater water efficiency could also be obtained by using a relatively inexpensive mode of water delivery know as multiple inlet irrigation. Multiple inlet irrigation is estimated to be in use on 38% of rice acres (Hardke and Wilson, 2013). Thus, the potential is available to increase water use efficiency in the state by greater adoption of multiple inlet irrigation based on these results.

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Table 1. Field characteristic variables used in the Tobit analysis.

Field characteristic	Description	N[a]	Mean
Field size	Size of field (acres)	98	51.49
2013	Field in Rice Research Verification Program in 2013	9	0.09
2012	Field in Rice Research Verification Program in 2012	8	0.08
2011	Field in Rice Research Verification Program in 2011	12	0.12
2010	Field in Rice Research Verification Program in 2010	9	0.09
2009	Field in Rice Research Verification Program in 2009	13	0.13
2008	Field in Rice Research Verification Program in 2008	12	0.12
2007	Field in Rice Research Verification Program in 2007	8	0.08
2006	Field in Rice Research Verification Program in 2006	12	0.12
2005	Field in Rice Research Verification Program in 2005	15	0.15
Northeast Region	Field in Northeast Arkansas (Statistical District 3)	36	0.37
Central East Region	Field in Central East Arkansas (Statistical District 6)	34	0.35
Other Locations	Field in location other than Northeast or Central East Arkansas	28	0.28
Non-hybrid rice[b]	Non-hybrid rice varieties	59	0.60
Hybrid rice	Hybrid rice varieties	39	0.40
Silt loam	Soils with silt loam texture	55	0.56
Clay	Soil with clay texture	43	0.44
Soybean	Soybean planted on field previous year	61	0.62
Other crop	Rice, grain sorghum, corn, fallow	37	0.38
Levees	Field contains contour or straight levees	80	0.82
No levees[c]	Field is either zero-grade or furrow irrigated	18	0.18
Well	Water comes from a well	81	0.83
Surface water	Water comes from a reservoir or stream	17	0.17
Diesel	Irrigation power unit is diesel	77	0.79
Electric	Irrigation power unit is electric	21	0.21
Multiple inlet	Field using poly pipe to irrigate paddies	31	0.32
No multiple inlet	Field without poly pipe	67	0.68

[a] N = number of fields.

[b] ‘Non-hybrid rice’ included fields with conventional, pure-line, long-grain rice (41 fields), conventional, pure-line, medium-grain rice (8 fields), and Clearfield, pure-line rice (10 fields) rice varieties; ‘Hybrid rice’ included fields with either hybrid varieties (11 fields) or Clearfield-hybrid varieties (28 fields).

[c] Fourteen zero-grade fields and four furrow-irrigated fields included in the ‘No levees’ category.

Table 2. Tobit analysis of irrigation water overuse as a function of field characteristics.

Independent variables	Irrigation water overuse
Intercept	0.0138
	(0.1777)[a]
Field size	-0.0025
	(0.0016)
2012	0.0161
	(0.1683)
2011	-0.0281
	(0.1537)
2010	0.2443
	(0.1616)
2009	-0.3635**[b]
	(0.1710)
2008	-0.2054
	(0.1714)
2007	0.1292
	(0.1808)
2006	0.0482
	(0.1622)
2005	0.1484
	(0.1569)
Northeast Region	0.0032
	(0.1240)
Central East Region	-0.0931
	(0.1283)
Hybrid	-0.1333
	(0.0814)
Silt loam	0.3034***
	(0.1008)
Soybean	0.1038
	(0.0784)
Levees	0.2477**
	(0.1207)
Surface water	-0.2608**
	(0.1116)
Electric power	0.1596
	(0.0999)
Multiple inlet	-0.1823**
	(0.0866)
σ[c]	0.3085***
	(0.0311)
Observations	98
Log likelihood	-39.354

[a] Numbers in parentheses are standard errors.

[b] Asterisks ***, **, and * represent statistical significance at the 1%, 5%, and 10% levels, respectively.

[c] σ is the estimated standard error of the regression.

NOTES

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