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B. R. Wells Rice Research Studies 2009

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B.R. Wells

RICE RESEARCH STUDIES 2009

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

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UNIVERSITY OF ARKANSAS
DIVISION OF AGRICULTURE

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B.R. Wells
RICE
Research Studies
2009

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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.

FEATURED RICE COLLEAGUE

Phil Tacker

Phil Tacker was born April 22, 1956, in West Memphis, Ark. His folks farmed at Black Oak, just south of Marked Tree, until he was five years old. He remembers picking cotton into a flour sack that his mom fixed for him so he could go to the field with his dad. He also remembers his dad having geese to eat the grass in the cotton, and Phil would herd them in at lunch and get them back out after lunch.

In 1962, Phil's family moved from the Delta to the Ozark Foothills in Greenbrier, Ark. After graduating from Greenbrier High School, he enrolled at the University of Arkansas at Fayetteville in the fall of 1974. He was a member of FarmHouse Fraternity and lived in the house with young men from mostly rural backgrounds who worked their way through college. He says this produced some lifetime friendships that helped him mature and contributed to his having a special college experience. He received a B.S. degree in Agricultural Engineering in 1979 and started his master's degree work as a graduate assistant in the Agricultural Engineering Department of the College of Agriculture and Home Economics.

Phil and Susan Dallas of Vilonia were married in July 1980, he completed his M.S. degree requirements in 1982, and he was appointed to an engineering position with the University of Arkansas Division of Agriculture Cooperative Extension Service in Little Rock in August of 1982. The position was in soil and water management and it had been open for five years. This, coupled with the fact that irrigation was rapidly expanding since 1980, which was one of the driest summers on record, provided ample opportunity for Phil to establish an extension education program in irrigation water management.

Phil worked with researchers, extension specialists, county agents, and growers to develop resources that addressed the questions and problems growers were dealing with relative to drainage and irrigation. Phil says he realized early on that he could be most effective by working with county agents and growers in conducting on-farm demonstrations of recommended water management practices. This provided the opportunity to evaluate the practices on a farm scale so agents and growers could determine how the practices could be implemented on other fields and farms. It also provided Phil valuable on-farm experiences of learning from growers and sharing this information through meeting presentations and other outreach efforts.

"Another blessing was how this provided me the opportunity to travel much of the Delta and work with some of the finest people," Phil said.

Some of the resources and programs that came out of these efforts are as follows:

1) Crop irrigation scheduling recommendations and an "Irrigation Scheduling Computer Program" for cotton, corn, soybean and grain sorghum that is used in at least five other states.

2) Irrigation pumping plant testing to determine inefficiencies and ways to reduce pumping costs.

3) Proper selection and implementation of polypipe for irrigation when it first became available and started replacing the use of rigid aluminum and PVC pipe on the farm.

4) Development of "Multiple Inlet Rice Irrigation" as an alternative to conventional cascading of water from the top of the field to the bottom.

5) "Border Irrigation" as an alternative irrigation method for crops planted on relatively uniform sloping fields.

6) Publication for estimating irrigation pumping costs.

7) Implementation of the "Phaucet Computer Program" for designing efficient furrow irrigation systems with polypipe.

8) Spreadsheets for "Comparing and Evaluating Irrigation Pumping Costs" and for "Selecting the Proper Size of PVC Underground Irrigation Pipe."

Phil received the "Award for Advancement of Surface Irrigation" from the *American Society of Agricultural and Biological Engineers* in 2004. After almost 27 years with the Division of Agriculture, Phil took an early retirement at the end of June 2009 and is working on a half-time basis with Delta Plastics, which makes polypipe and is located in Little Rock. He is a technical advisor and support person to the sales staff.

Susan and Phil have two daughters, Brooke, 23, and Whitney, 25. Susan retired in June 2010 after 28 years as a speech therapist in public schools.

Phil says he is very thankful for his Extension career and realizes how blessed he is to have been able to keep one very fulfilling job for almost 27 years and remain close to family. He says he and Susan are further blessed with retirements at relatively young ages and in good health, with options to work part time while pursuing other interests such as Christian ministry opportunities.

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 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, (501) 575-5647.

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

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Trends in Arkansas Rice Production

C.E. Wilson, Jr., S.K. Runsick, and R. Mazzanti

ABSTRACT

Arkansas is the leading rice-producing state in the U.S., representing 45.5% of the total U.S. production and 47.4% of the total acres planted to rice in 2009. Rice cultural practices vary across the state and across the U.S. However, due to changing political, environmental, and economic times, these practices are dynamic. This survey was initiated in 2002 to monitor how the changing times reflect the 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 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-producing state in the U.S., representing 45.5% of the total U.S. production and 47.4% of the total acres planted to rice in 2009. Rice cultural practices vary across the state and across the U.S. However, due to changing political, environmental, and economic times, the practices are dynamic. This survey was initiated in 2002 to monitor how the changing times reflect the changes in the way Arkansas rice producers approach their livelihood. It also serves to provide information to researchers and extension personnel about the ever-changing challenges facing Arkansas rice producers.

MATERIALS AND METHODS

A survey has been conducted annually since 2002, by polling county 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 Rice DD50 program enrollment.

RESULTS AND DISCUSSION

Rice acreage by county is presented in Table 1 with distribution of the most widely-produced varieties. 'Wells' was the most widely planted variety in 2009 at 16.5% of the acreage, followed by 'Rice Tec CL XL 729' (15.1%), 'Jupiter' (12.5%), 'CL 151' (11.8%), and 'Francis' (9.6%). The acreage planted to Wells decreased from a high of 45% in 2003 to 16.5% in 2009. The biggest changes in 2009 were the increase in CL 151 and Jupiter. Medium-grain acreage more than doubled in 2009 from 100,000 acres in 2008 to almost 225,000 acres in 2009, mostly Jupiter. The adoption of the Clearfield rice system represents a significant factor that plays an important role in the management of red rice. Clearfield rice (all varieties combined) accounted for over 45% of the total rice acreage in 2009, and is up from just over 40% in 2008 (Fig. 1). Clearfield rice has increased in acreage each year after its launch, except for 2007. Based on seed supply and other market-related issues, the 2010 Clearfield rice acreage is poised to exceed 60% of the total Arkansas rice acreage. The stewardship program that was implemented to reduce problems associated with out-crossing with red rice has been effective when used. However, in areas where suggested crop rotations have not been followed, imidazolinone-resistant barnyardgrass has been discovered. When barnyardgrass is no longer controlled effectively with the technology, the program will become much less attractive.

Arkansas' planted rice acreage represented 47.4% of the total 2009 US rice crop (Table 2). The state-average yield of 6,800 lb/acre (151 bu/acre) was a 2% increase in average yield from the 2008 crop but was 6% less than the record yield of 7,230 lb/acre established during 2007. The average yields in Arkansas represented the third highest average in the U.S. behind California and Texas. Lower yields observed during 2008 and 2009 can be attributed to delayed planting because of spring rainfall (Fig. 2). The total rice produced in Arkansas during 2009 was 99.9 million hundredweight (cwt). This represents 45.5% of the 219.9 million cwt produced in the U.S. during 2009. All of the other southern states increased overall production compared to 2008 by an average of 8%. Over the past three years, Arkansas has produced 47.6% of all rice produced in the U.S. The five largest rice-producing counties in 2009 included Poinsett, Arkansas, Lawrence, Cross, and Jackson, representing 35.4% of the state's total rice acreage (Table 1).

Planting began in 2009 much later than the 5-year average due to wet weather during the end of March and beginning of April (Fig. 2). Approximately 25% of the crop is normally planted by 15 April and yet in 2009 only about 15% had been planted by this date. The delay resulted in an average of 2 wk later planting compared to normal but was as much as 4 wk in some areas. Almost no rice was planted between 6 May and 20 May. Because of the planting delays and cool temperatures during the growing season, harvest was also delayed compared to normal (Fig. 3). Typically half of the crop is harvested by 25 Sept., yet during 2009, only 25% of the crop had been harvested by this date. Harvest is usually almost complete by 1 Nov. and yet in 2009, almost 20% of the crop was still in the field.

Approximately 53% of the rice produced in Arkansas was planted using conventional tillage methods in 2009 (Table 3). This usually involves fall tillage when the weather cooperates, followed by spring tillage to prepare the seedbed. This is a slight decrease compared to 2008. The most common conservation tillage system utilized by Arkansas rice farmers is stale seedbed planting following fall tillage, representing approximately 35% of the state's rice acreage. True no-till rice production is not common but is done in a few select regions of the state. According to the survey, no-till rice production increased slightly compared to previous years and accounted for approximately 12% of the rice acreage in 2009.

The majority of rice is still produced on silt loam soils (Table 3). However, an increasingly more important factor is the amount of rice produced on clay or clay loam soils (27% and 21% of the acreage, respectively). This represents unique challenges in rice-production issues, such as tillage, seeding rates, fertilizer management, and irrigation. The increase in rice acreage on clay soils has been observed in counties along the Mississippi River, where historically non-irrigated soybeans have dominated. For example rice production in Mississippi County has more than doubled over the last 20 years, increasing from approximately 15,000 acres in 1984 to about 44,000 acres in 2009 (Arkansas Agricultural Statistics, 1984; Table 1). Also, the 2009 acreage was down from the high of 49,000 acres in 2005. Other areas where rice production on clay soils have increased during this time frame include Crittenden County, and the eastern half of Poinsett, Cross, and St. Francis counties.

Rice most commonly follows soybean in rotation, accounting for almost 68% of the rice acreage (Table 3). Approximately 28% of the acreage in 2009 was planted following rice, with the remaining 4% made up of rotation with other crops including corn, grain sorghum, cotton, wheat, oats, and fallow. The majority of the rice in Arkansas is produced in a dry-seeded, delayed-flood system with only approximately 8% using a water-seeded system. Approximately three fourths of all the Arkansas rice acreage is drill-seeded, with an additional 23% broadcast-seeded in a delayed-flood system.

Irrigation water is one of the most precious resources for rice farmers of Arkansas. Reports of diminishing supplies have prompted many producers to develop reservoir and/or tailwater recovery systems to reduce the "waste" by collecting and re-using all available water. Simultaneously, producers have tried to implement other conservation techniques to preserve the resource vital to continued production. Approximately 83% of the rice acreage in Arkansas is irrigated with groundwater, with the remaining 17% irrigated with surface water obtained from reservoirs or streams and bayous (Table 3).

During the mid 1990s, the University of Arkansas began educating producers on the use of poly-tubing as a means of irrigating rice to conserve water and labor. As of 2009, rice farmers have adopted this practice on more than 42% of the rice acreage. The adoption of multiple-inlet irrigation using poly-tubing has increased from 17% in 2002 (Fig. 4). Approximately 56% of the rice is still irrigated with conventional levee and gate systems. A small percentage of rice acreage is produced in more upland conditions utilizing furrow-irrigation systems and sprinkler/pivot systems.

Stubble management is important for preparing the fields for the next crop, particularly in rice following rice systems (Table 3). Several approaches are utilized to manage the rice straw for the next crop, including tillage, burning, rolling, and winter flooding. Approximately 15% of the acreage was burned, 24% was tilled, 33% was rolled, and 20% was winter flooded. Combinations of these systems were 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. For example, heavy rainfall during 2009 significantly reduced the number of acres that were burned.

SIGNIFICANCE OF FINDINGS

During the past 20 years, the state-average yields in Arkansas have increased approximately 1780 lb/acre (about 40 bu/acre) or 2 bu/acre/year. This increase can be attributed to improved varieties and improved management, including such things as better herbicides, fungicides, and insecticides, improved water management through precision leveling and multiple inlet poly-pipe irrigation, improved fertilizer efficiency, and increased understanding of other practices such as seeding dates and tillage practices. Collecting this kind of information regarding rice production practices in Arkansas is important for researchers to understand the adoption of certain practices as well as to understand the challenges and limitations faced by producers in field situations.

ACKNOWLEDGMENTS

The authors would like to extend thanks to all of the county extension 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. Arkansas harvested

County/	Harvested acreage[z]		Medium-grain			
Parish	2008	2009	Bengal	Jupiter	Others[y]	Cheniere
Arkansas	102,747	113,149	2,024	6,476	1,315	6,845
Ashley	12,713	14,968	256	0	0	0
Chicot	31,961	36,910	0	211	0	2,666
Clay	75,255	77,262	69	9,015	208	3,709
Craighead	78,477	79,299	0	15,146	505	3,127
Crittenden	36,935	37,391	1,193	7,266	0	75
Cross	79,819	90,169	1,818	13,532	808	0
Desha	26,660	34,613	1,613	3,134	0	3,995
Drew	12,441	12,761	815	1,133	0	0
Faulkner	2,839	1,742	0	0	0	0
Greene	77,459	72,790	3,326	0	0	1,550
Independence	10,177	8,750	34	173	0	111
Jackson	95,396	89,485	3,419	26,326	2,413	745
Jefferson	67,424	69,668	524	899	225	7,178
Lafayette	1,869	3,089	0	0	0	34
Lawrence	102,405	105,967	0	15,500	567	5,723
Lee	22,840	25,951	1,515	2,545	0	877
Lincoln	29,337	30,785	0	611	0	2,803
Lonoke	75,138	79,914	1,971	3,704	3,106	12,537
Miller	1,665	1,530	0	0	0	1,530
Mississippi	36,715	44,462	120	1,438	0	0
Monroe	52,358	57,066	1,308	3,489	1,122	10,519
Phillips	35,395	32,783	199	800	0	0
Poinsett	116,371	122,004	5,592	39,142	1,004	1,173
Prairie	60,594	62,656	307	11,047	1,473	6,013
Pulaski	3,246	3,624	0	0	0	0
Randolph	33,033	36,170	208	4,542	0	3,057
St. Francis	38,492	42,921	579	8,691	0	2,141
White	13,943	12,721	329	2,713	79	953
Woodruff	54,990	51,908	258	4,983	0	1,092
Others	5,159	5,497	0	253	0	0
Unaccounted	0	11,995	0	0	0	0
2009 Total		1,470,000	27,476	182,768	12,826	78,455
2009 Percent		100.00%	1.88%	12.54%	0.88%	5.38%
2008 Total	1,393,854		14,311	86,646	208	28860
2008 Percent	100.00%		1.03%	6.22%	0.01%	2.07%

[z] Harvested acreage. Source: Arkansas Agricultural Statistics and FSA

[y] Other varieties: AB647, Arize QM1003, Catahoula, CL 131, CL 161, Cybonnet , Cypress, Della, Dellrose, Jasmine 85, Koshihikari, Neptune, Nortai, Pirogue, Rice Tec CL XL 730, Rice Tec CL XL 746, Rice Tec CL XL 751, Rice Tec XL 723, Taggart, Templeton, and Trenasse .

[x] Other counties: Clark, Conway, Hot Spring, Little River, Perry, Pope, and Yell.

[w] Unaccounted for acres is the total difference between USDA-NASS harvested acreage estimate and preliminary estimates obtained from each county FSA. Source: Arkansas Argicultural Statistics and FSA.

rice acreage 2009 summary.

Long-grain						
CL 151	CL 171 AR	Francis	CL XL 729	CL XL 745	Wells	Others[x]
12,004	2,022	33,696	9,688	7,055	14,216	17,808
1,750	540	0	5,742	1,167	2,457	3,055
1,949	1,493	167	9,529	2,666	4,098	14,132
16,895	4,835	1,923	14,835	8,241	8,379	9,153
14,470	12,454	732	6,986	5,788	12,042	8,050
1,189	604	0	2,416	6,115	17,854	679
17,121	12,064	10,861	7,471	6,503	13,559	6,433
9,010	0	2,431	6,901	2,123	2,878	2,528
2,184	0	0	815	1,941	874	4,999
0	0	0	0	726	910	106
7,361	8,575	4,455	29,508	8,975	4,003	5,036
1,259	1,106	198	2,457	1,012	1,012	1,389
8,449	7,422	1,325	16,484	6,792	6,792	9,319
7,516	0	4,808	11,647	880	16,861	19,130
0	0	0	0	0	0	3,055
10,509	5,684	1,381	28,812	11,939	14,505	11,347
413	3,087	8,243	2,205	727	3,934	2,405
0	0	10,761	4,009	5,908	6,692	0
13,335	2,675	7,294	11,549	6,762	9,953	7,028
0	0	0	0	0	0	0
9,063	2,874	0	980	735	25,394	3,858
3,718	176	12,282	9,968	991	10,409	3,084
0	7,444	11,651	0	0	961	11,728
15,058	6,258	7,301	8,083	10,169	25,031	3,194
4,116	4,671	5,838	8,466	2,919	7,064	10,742
0	0	0	0	0	3,624	0
5,649	4,295	0	2,722	10,887	0	4,810
1,356	2,512	6,233	1,475	0	18,317	1,618
839	244	0	4,411	1,513	0	1,640
7,002	2,225	8,491	11,371	5,562	8,541	2,384
274	493	275	2205	364	420	1,213
0	0	0	0	0	0	0
172,488	93,751	140,345	220,733	118,461	240,778	169,923
11.83%	6.43%	9.63%	15.14%	8.12%	16.51%	11.65%
--	191,940	164,708	204,517	27,053	350,434	325,178
0.00%	13.77%	11.82%	14.67%	1.94%	25.14%	23.33%

Table 2. Acreage, grain yield, and production of rice in the United States from 2007 to 2009[z].

	Area planted			Area harvested			Yield			Production		
State	2007	2008	2009	2007	2008	2009	2007	2008	2009	2007	2008	2009
	(1,000 acres)						(lb/acre)			(1,000 cwt[y])		
AR	1,331	1,401	1,486	1,325	1,395	1,470	7,230	6,660	6,800	95,814	92,938	99,924
CA	534	519	561	533	517	556	8,200	8,320	8,600	43,684	43,030	47,804
LA	380	470	470	378	464	464	6,140	5,830	6,300	23,222	27,037	29,217
MS	190	230	245	189	229	243	7,350	6,850	6,700	13,892	15,687	16,281
MO	180	200	202	178	199	200	6,900	6,620	6,710	12,279	13,173	13,423
TX	146	175	171	145	172	170	6,550	6,900	7,770	9,497	11,868	13,201
US	2,761	2,995	3,135	2,748	2,976	3,103	7,219	6,846	7,085	198,388	203,733	219,850

[z] Source: USDA-NASS, 2009.

[y] cwt = hundredweight.

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

	2007		2008		2009	
Cultural practice	Acreage	% of total	Acreage	% of total	Acreage	% of total
Arkansas rice acreage	1,327,106	100.00	1,393,000	100.00	1,470,000	100.00
Soil texture						
Clay	309,150	22.9	287,612	20.6	398,397	27.1
Clay loam	225,450	16.7	285,532	20.5	304,290	20.7
Silt loam	713,350	52.1	760,351	54.6	710,010	48.3
Sandy loam	70,200	5.2	51,523	3.7	52,269	3.6
Sand	41,850	3.1	7,865	0.6	4,462	0.3
Tillage practices						
Conventional	742.500	55.0	802,478	57.6	771,026	52.5
Stale seedbed	484.650	35.9	372,150	26.7	519,311	35.3
No-till	122.850	9.1	218,372	15.7	179,663	12.2
Crop rotations						
Soybean	1,061,100	78.6	1,027,192	73.7	995,026	67.7
Rice	193,860	14.4	308,748	22.2	409,318	27.8

continued

Table 3. Continued.

Cultural practice	2007 Acreage	2007 % of total	2008 Acreage	2008 % of total	2009 Acreage	2009 % of total
Crop rotations - continued						
Cotton	14,850	1.1	9,014	0.6	13,588	0.9
Corn	31,050	2.3	32,885	2.4	44,471	3.0
Grain sorghum	10,800	0.8	8,869	0.6	3,524	0.2
Wheat	21,600	1.2	1,819	0.1	2,631	0.2
Fallow	21,600	1.6	4,459	0.3	13,375	0.9
Oats	157	<0.1	0	0.0	0	0.0
Seeding methods						
Drill seeded	1,031,400	76.4	1,085670	77.9	1,008,112	68.6
Broadcast seeded	261,900	19.4	276.585	19.8	314,557	23.2
Water seeded	56,700	4.2	31,088	2.2	120,332	8.2
Irrigation water sources						
Groundwater	1,084,050	80.3	1.093.675	78.5	1,218,942	82.9
Stream, rivers, etc.	128,250	9.5	120.585	8.7	114,660	7.8
Reservoirs	137,700	10.2	178.610	12.8	136,747	9.3
Irrigation methods						
Flood, levees	928,800	68.8	842,609	60.5	835,504	56.8
Flood, multiple inlet	413,100	30.6	506,864	36.4	627,176	42.7
Furrow	8,100	0.6	43,512	3.1	7,607	0.5
Sprinkler	0	0.0	0	0.0	178	0.0
Stubble management						
Burned	313,875	23.3	363,820	26.1	225,883	15.4
Tilled	404,325	30.0	358,348	25.7	352,505	24.0
Rolled	409,725	30.4	551,154	39.6	491,196	33.4
Winter flooded	281,475	20.9	316,776	22.7	286,971	19.5

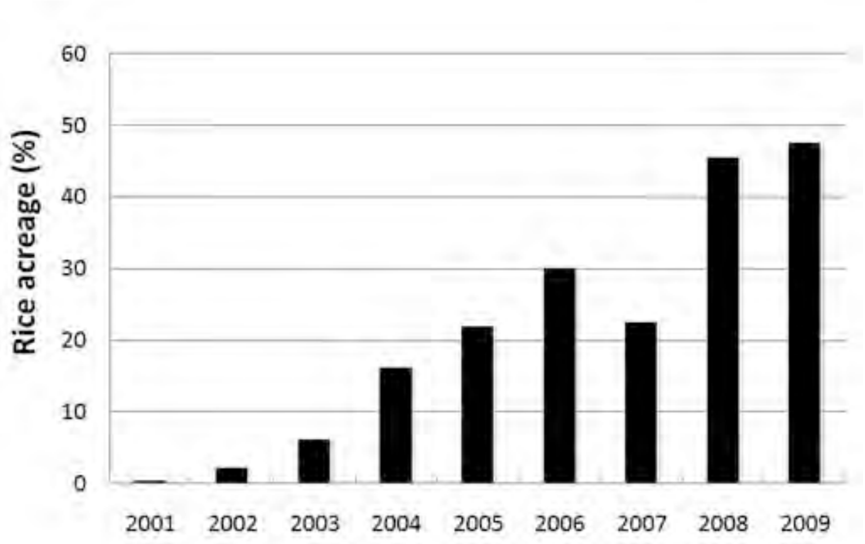

Fig. 1. Percentage of rice planted in Arkansas to Clearfield rice varieties between 2001 and 2009.

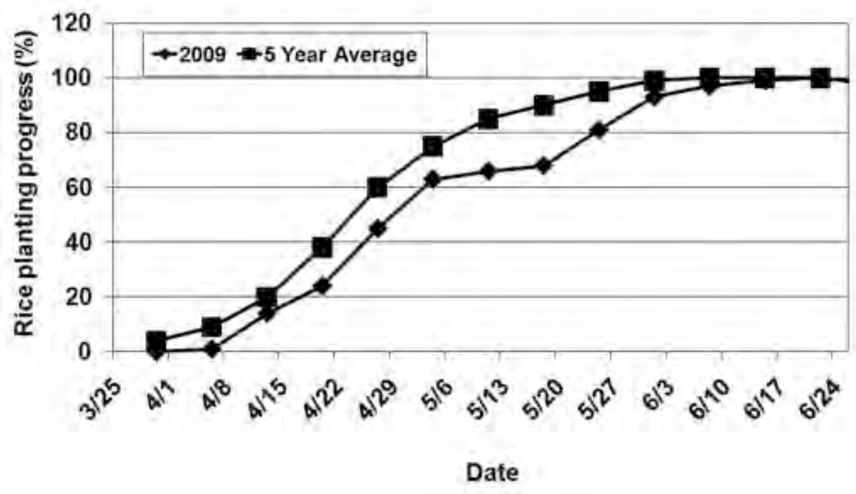

Fig. 2. Arkansas rice planting progress during 2009 compared to the five-year average. (Data obtained from NASS, 2009).

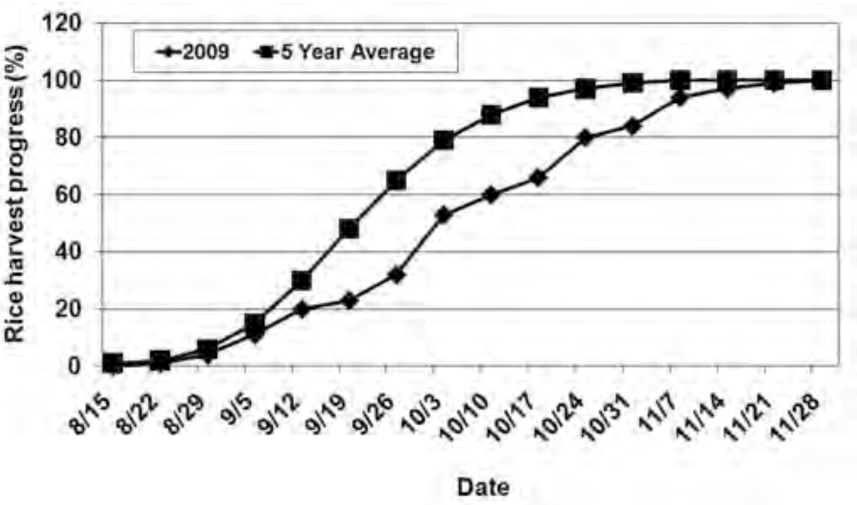

Fig. 3. Rice harvest progress during 2009 compared to the five-year average. (Data obtained from NASS, 2009).

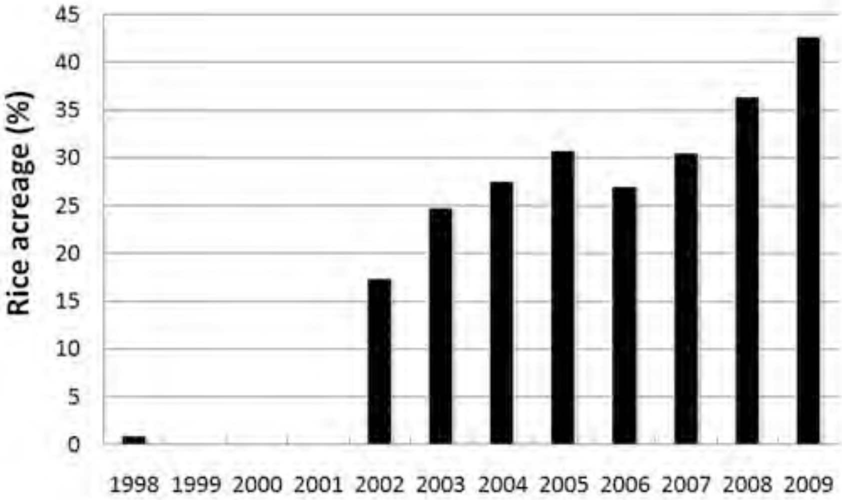

Fig. 4. Adoption of multiple-inlet rice irrigation using poly tubing in Arkansas since 1998.

OVERVIEW AND VERIFICATION

2009 RICE RESEARCH VERIFICATION PROGRAM

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ABSTRACT

The 2009 Rice Research Verification Program (RRVP) was conducted on twenty-two commercial rice fields across the state. Counties participating in the program included Arkansas, Ashley, Chicot, Clark, Clay, Crittenden, Cross, Desha, Drew, Jackson, Jefferson, Lawrence, Lee, Lincoln, Lonoke, Mississippi, Poinsett (2 fields), Prairie (2 fields), Randolph, and White for a total of 1286 acres. Grain yield in the 2009 RRVP averaged 180 bu/acre ranging from 145 to 216 bu/acre. The 2009 RRVP average yield was 30 bu/acre greater than the estimated Arkansas state average of 150 bu/acre. The highest yielding field was in Chicot County with a grain yield of 216 bu/acre. The lowest yielding field was in Crittenden County and produced 145 bu/acre. Milling quality in the RRVP was comparable with milling from the Arkansas Rice Performance Trials and averaged 61/70 (i.e., head rice/total white rice).

INTRODUCTION

In 1983, the 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 University of Arkansas 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 University of Arkansas 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 Extension educational programs at the county and state level. Since 1983, the RRVP has been conducted on 319 commercial rice fields in 33 rice-producing counties in Arkansas. The program has typically averaged about 20 bu/acre better than the state average. This increase in yield over the state average can mainly be attributed to intensive cultural management and integrated pest management.

PROCEDURES

The RRVP fields and cooperators are selected prior to the beginning of the growing season. Cooperators agree to pay production expenses, provide expense data, and implement university recommendations in a timely manner from planting to harvest. A designated county agent from each county assists the RRVP coordinator in collecting data, scouting the field, and maintaining regular contact with the producer. Weekly visits by the coordinator and county agents 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 university 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 2009 included Arkansas, Ashley, Chicot, Clark, Clay, Crittenden, Cross, Desha, Drew, Jackson, Jefferson, Lawrence, Lee, Lincoln, Lonoke, Mississippi, Poinsett (2 fields), Prairie (2 fields), Randolph, and White. The twenty-two rice fields totaled 1286 acres enrolled in the program. Eight varieties were seeded (‘Cheniere’, ‘CL 151’, ‘CL XL 729’, ‘CL XL 745’, ‘CL XL 746’, ‘Jupiter’, ‘Wells’, and ‘XL 723’) in the 22 fields and University of Arkansas recommendations were used to manage the RRVP fields. Agronomic and pest management decisions were based on field history, soil test results, variety, and data collected from individual fields during the growing season. An integrated pest-management philosophy is utilized based on University of Arkansas recommendations. Data collected included components such as stand density, weed populations, disease infestation levels, insect populations, temperature, rainfall, irrigation amounts, dates for specific growth stages, grain yield, milling yield, and grain quality.

RESULTS

Yield

The average RRVP yield was 180 bu/acre with a range of 145 to 216 bu/acre (Table 1). The RRVP average yield was 30 bu/acre more than the estimated state average yield of 150 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

University of Arkansas recommendations. The 2009 RRVP average yield was 9 bu/acre less than the programs highest average yield of 189 bu/acre that was set in 2007. The highest yielding field achieved 216 bu/acre and was seeded with CL XL 729 in Chicot County. Six additional fields, Ashley, Clay, Cross, Jackson, Lee and Mississippi counties, exceeded 200 bu/acre and nine fields exceeded 190 bu/acre. The lowest yielding field obtained 145 bu/acre and was seeded with Wells in Crittenden County.

Milling data was recorded on all of the RRVP fields. The average milling yield for the 22 fields was 61/70 (head rice/total white rice) with the highest milling yield of 69/73 occurring in Poinsett 1 County (Table 1). The milling yield of 55/70 is considered the standard used by the rice milling industry. The lowest milling yield was 50/66 and occurred in the Drew County field of CL XL 729.

Planting and Emergence

Planting began with Cross and Jackson Counties on 7 April and ended with Clay, Drew, and White counties planted 22 May (Table 2). The majority of the verification fields were planted in mid to late April. An average of 55 lb/acre was seeded in the RRVP fields. Seeding rates were determined with the Cooperative Extension Service RICESEED program for all fields. An average of 13 days was required for emergence and stand density ranged from 4 to 34 plants/ft^2, with an average of 13 plants/ft^2. The seeding rates in some fields were higher than average due to planting method and soil texture. Broadcast seeding and clay soils require an elevated seeding rate.

Irrigation

Well water was used to irrigate 17 of the 22 fields in the 2009 RRVP. Arkansas, Clark, Poinsett (1), Randolph, and White counties were irrigated with surface water. The Lawrence County field was a zero grade field and the Jefferson County field was furrow irrigated. Twelve fields (Ashley, Chicot, Clark, Clay, Crittenden, Cross, Desha, Jackson, Lee, Lincoln, Mississippi, and White counties) used multiple inlet (MI) irrigation either by utilizing irrigation tubing or by having multiple risers or water sources. Flow meters were used in 13 of the fields to record water usage throughout the growing season. In fields where flow meters were not utilized, an average of 26 acre-inches was used.

An average of 26 acre-inches of water was used across all irrigation methods (Table 2). The zero grade field (15 acre-inches) and furrow-irrigated field (15 acre-inches) used the least amount of water for irrigation. The fields with MI irrigation averaged 28 acre-inches of water, however, many of those fields did not have flow meters and the average was used. Difference in water used was due in part to rainfall amounts which ranged from 14 to 39 inches. Typically a 25% reduction in water used is seen when using MI irrigation.

Fertilization

Nitrogen recommendations were based on a combination of factors including soil texture, previous crop and variety requirements (Table 3). Nitrogen rates can appear high in some fields where rice was the previous crop and the soil texture was a clay soil texture. These factors increase the nitrogen requirements significantly compared to a silt loam soil where soybeans were the previous crop.

Ammonium sulfate (21-0-24) was applied in some fields at the 2- to 3-leaf stage as a management tool to speed height development and shorten the time required to get the rice to flood stage or to correct sulfur deficiencies (Table 3). Ammonium sulfate was applied at a rate of 100 lb/acre in Chicot, Clark, Crittenden, Lincoln, Lonoke, and Poinsett 1 counties and at a rate of 150 lb/acre in Jefferson County.

Phosphorus (P), potassium (K), and zinc (Zn) were applied based on soil test results (Table 3). Phosphorus and/or K and Zn were applied preplant in most of the fields. Phosphorus was applied to Desha, Jackson, Jefferson, Lincoln, Prairie 1, and Prairie 2 counties in the form of diammonium phosphate (DAP; 18-46-0). Zinc was applied as a seed treatment in fields with hybrid rice varieties at a rate of 0.5 lb Zn/60 lb seed. The average cost of fertilizer across all fields was $166.18 (Table 4) which was $37.30 less than 2008.

Weed Control

In 2009, the herbicide costs ranged from $48.46/acre in Poinsett 2 County to $118.68/acre in Jefferson County with an average herbicide cost of $79.22/acre (Table 4). Command was utilized in 15 of the 22 fields for early-season grass control (Table 5). Facet was applied in 2 fields (Crittenden and Jackson counties) pre-emergence and in 7 fields (Arkansas, Ashley, Chicot, Clark, Jefferson, Lee, and Randolph counties) early post-emergence. Four fields (Clark, Drew, Jackson, and Randolph counties) did not utilize a herbicide for pre-emergence weed control. Thirteen fields, (Ashley, Chicot, Clark, Clay, Drew, Jackson, Jefferson, Lawrence, Lincoln, Lonoke, Mississippi, Randolph, and White counties) were seeded in Clearfield varieties and Newpath was 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

Fungicides were applied to five of the fields in 2009 for control of sheath blight and/or blast (Table 6). The average cost for fungicide was $9.05/acre (Table 4). The five fields treated were seeded in non-hybrid varieties. The Crittenden County field of Wells was treated for blast. The Poinsett 1 County field was treated with Bumper fungicide for the prevention of kernel smut as the field has had a history of the disease. Quadris, or Stratego was used to control sheath blight and blast and rates were determined based on variety, growth stage, climate, disease incidence/severity, and disease history (Table 6).

Insect Control

The Prairie 1 County field required treatment for rice water weevil (Table 6). Four fields, all of which were in south Arkansas, (Ashley, Chicot, Clark, and Prairie (2) counties) were treated for rice stink bug. Five fields (Arkansas, Cross, Lee, Prairie 2, and White counties) had Cruiser seed treatment applied to the seed which provided excellent emergence, stand density, and vigor. The average cost for insecticides was $2.41/acre (Table 4).

Economic Analysis

This section provides information on the development of estimated production costs for the 2009 RRVP. Records of operations on each field provided the basis for estimating these costs. The field records were compiled by participating county extension faculty, the coordinator of the RRVP, and the producers for each field. Presented in this analysis are specified variable costs, specified ownership costs and total costs for each field. Break-even prices for the various cost components and returns above specified variable expenses at the average 2009 harvest price and adjusted for milling yield are also presented.

Specified variable costs are those expenditures that would generally require annual cash outlays and would be included on an annual operating loan application (Table 4). Actual quantities of all operating inputs were used in this analysis along with input prices collected for use in the Arkansas Cooperative Extension Service 2009 Rice Budgets with updated urea-N, K, P, and diesel prices to match spring 2009 input prices. All selected variables presented in Table 4, other than seed cost, decreased from the previous year. This is mostly due to a drop in diesel and fertilizer prices. Seed cost increased from the previous year due to a larger share of CL hybrids being planted in verification fields.

The producers' actual field operations were used as a basis for calculations and actual equipment sizes and types were matched as closely as possible. Fuel and repair costs were calculated by extension models based on the size or horsepower of the equipment. A diesel price of $2.00/gal was used for 2009 ($4.25/gal was used for 2008, Table 4). Producers' actual machinery costs may vary from the machinery cost estimates that are presented in this report. Specified variable costs for the 2009 RRVP fields averaged $101/acre less than the 2008 average and ranged from $413/acre for Desha County to $739/acre for Lonoke County with an overall acre weighted average of $572/acre (Table 7).

Land costs incurred by producers participating in the RRVP would likely vary from land ownership, cash rent, or some form of crop share arrangement. Therefore, a comparison of these divergent cost structures would contribute little to this analysis.

For this reason, a 20% crop share rent was assumed to provide a consistent standard for comparison. This is not meant to imply that this arrangement is normal or that it should be used in place of existing arrangements. It is simply a consistent measure to be used across all RRVP fields. The average break-even price needed to cover specified variable costs including the assumed 20% crop share rent was \$3.87/bu, which is \$1.02/bu less than the \$4.89 price required in 2008. Furthermore, break-even prices to cover variable costs ranged from \$3.05/bu in Desha County up to \$5.17/bu in Lonoke County (Table 7).

Table 7 includes estimated net returns above specified variable costs and total costs. Net land costs and impacts of milling yields on gross returns are also included. Estimated landowner returns or net land costs were calculated assuming the landowner pays 20% of the drying expenses and all irrigation system fixed costs at \$30.59/acre for a typical well or \$24.95/acre for a re-lift system. Arkansas, Clark, Poinsett 1, Randolph, and White counties used a re-lift irrigation system to pump surface water. Costs for risk, overhead, and management were not included in the analysis.

Arkansas average long-grain September cash price was estimated at \$5.70/bu, which was \$1.80/bu less than the 2008 estimated price of \$7.50/bu. The verification program had four fields planted in medium-grain varieties (Table 1). It is estimated that the average medium-grain price contracted in Arkansas was \$7.00/bu. A premium or discount was given to each farm based upon the milling yield. A standard milling of 55/70 would generate \$5.70/bu for long-grain and \$7.00/bu for medium-grain. Broken rice is assumed to have 70% of whole price value. If milling yield is higher than the standard, a premium is made while a discount will be given for milling less than standard. The 2009 average premium per acre was greater than the 2008 premium by \$32.78/acre. Estimated long-grain prices adjusted for milling yield varied from \$5.33/bu in Drew County to \$6.25/bu in Poinsett 1 County (Table 7). Medium-grain prices adjusted for milling yield varied from \$6.85/bu in Poinsett 2 County to \$7.57/bu in Lee County.

Returns above variable costs ranged from \$41/acre in Lonoke County to \$648/acre profit in Lee County (Table 7). Profits averaged \$37/acre or 10% less than 2008 due to a decrease in crop price of \$1.33/bu or 17.7%, but increased yields, higher milling yields and decreased variable costs helped offset some of the price decline. Growing medium-grain rice helped profits due to the higher price relative to long-grain rice. The top five fields with the highest returns above variable cost were Lee, Cross, Prairie 1, Mississippi, and Poinsett 2 counties. Four of the five top fields were planted in medium-grain rice.

DISCUSSION

Field Summaries

The Arkansas County field was 42-acres made up of a silty clay loam soil. The field was seeded on 23 April in RT XL 723 at a rate of 30 lb/acre. The seed was treated with Cruiser insecticide and the stand density was 14 plants/ft^2. Two tons of chicken litter was applied preplant and urea was applied pre-flood at 200 lb/acre followed by

70 lb/acre at the late boot stage. Command, Facet, and Prowl herbicides were applied at the 2- to 3-leaf stage followed by RicePro and Permit prior to flooding. The yield was a respectable 192 bu/acre.

The Ashley County field was planted in the Overflow National Wildlife Refuge. The 44-acre field had historic yields of 130 to 160 bu/acre. The field was seeded in CL XL 729 on 1 May. The soil was a clay with a seeding rate of 40 lb/acre that resulted in a stand density of 10 plants/ft^2. Urea was applied pre-flood at 270 lb/acre followed by 100 lb/acre at the late boot stage. There were numerous weed challenges in the wildlife refuge yet the Newpath and Facet herbicides followed by Newpath and Aim kept the field weed free. The levees were not seeded and coffeebean escapes were prevalent and later controlled with Blazer herbicide. Stink bugs reached threshold levels and were controlled with Karate. The yield was a field record of 201 bu/acre.

The Chicot County field was 41 acres of clay soil. The chosen variety was CL XL 729, seeded at 33 lb/acre, and planted on 23 April. The stand appeared very thin but the plant density was 9 plants/ft^2. No K or P fertilizer was necessary according to the soil sample, however ammonium sulfate was applied at 100 lb/acre. Nitrogen was applied at 200 lb/acre pre-flood followed by 70 lb/acre at the late boot stage. The field reached threshold levels for stink bugs and was sprayed with Karate. The Chicot County field was the highest yielding in the 2009 Rice Research Verification Program at 216 bu/acre.

Clark County was a 72 acre silty clay loam field. The row spacing was 10-in. and the previous crop was corn. The past rice yields had been from 130 to 165 bu/acre. The variety of choice was CL XL 745 and was planted on 26 April. The seeding rate was 30 lb/acre with a stand density of 8 plants/ft^2. There were areas where the drill went too deep and the stand was thin and vigor was low resulting in delayed growth. The fertilizer applied was 0-40-60 preplant followed by DAP and ammonium sulfate at 100 lb/acre applied at the 2- to 3-leaf stage. Urea-N was applied at 270 lb/acre pre-flood and 100 lb/acre in the late boot stage. The herbicides Newpath and Facet kept the field weed free. The insecticide used was Karate for late-emerging stink bugs. Due to the weather in 2009 the field remained 7 to 10 days behind the DD50. Despite the planting and weather issues the field yielded a record 193 bu/acre.

Clay County was one of the latest planted and highest yielding fields in the program. It was seeded 22 May in CL XL 745 at a rate of 31 lb/acre and yielded 209 bu/acre. Everything was done by the book, with no problems. Two applications of Newpath and a little Permit for nutsedge is all it took to keep the field weed free. The stand was excellent and very uniform. The field looked good all year. The cool weather delayed maturing by a couple of weeks, as was the case in most of the fields.

This was the second year for the Crittenden County field to be in the program. The field was leveled 2 years ago and part of this field was an old cotton field and has a very poor soil. About half of the field grows good rice and it is easy to identify the cut areas. It is going to take some poultry litter and a few years to make it productive. The field was broadcast seeded in Wells. As is the case a lot of times with broadcast seeding there were some holes and thin areas. It was dry in June and the field crusted over. Some areas were struggling to establish a stand. The authors recommended flushing the field, but it rained soon after. The Facet applied pre-emergence controlled the grass for a long time. The plan was to apply Propanil then fertilize and flood. It rained following the Propanil application and it was a couple of weeks before the fertilizer could be applied. Another flush of barnyardgrass came up prior to flooding and an application of Ricestar was required. Leaf blast was present in the field and continued to worsen as weather conditions were favorable. The field was treated at 10% heading with Stratego and no significant yield loss occurred from the disease. The yield of 145 bu/acre was an improvement over last year's 138. The authors really expected it to be 20 bushels better than that, but the thin areas really dropped the average.

When the authors looked at the soil test results from the Cross County field back in the winter, they were concerned. The pH was 8.1 and the soil-test Zn and K were very low, not a great combination for rice. A few weeks later, however, we had the field of Jupiter picked to be the highest-yielding field and the yield was excellent at 203 bu/acre. The seed was treated with Zn and Cruiser insecticide. The emergence and vigor were excellent, but after the flood was established the rice exhibited Zn chlorotic deficiency symptoms. The flood was lowered and Zn applied quickly. After that, the rice recovered and grew well. Sheath blight became aggressive late, just prior to heading and a low rate of Quadris was applied and protected the crop through heading.

The Desha County field was 43 acres of a clay soil. The variety of choice was Wells with Zn seed treatment applied. The planting date was 22 April with a seeding rate of 123 lb/acre. The stand density was 18 plants/ft^2 and the herbicides Rice Pro and Command did a good job on the grass. Nutsedge was scattered but didn't justify an application. The fertilizer applied pre-flood was urea at 200 lb/acre and DAP at 100 lb/acre followed by urea applied at 100 lb/acre at mid-season. No insecticide or fungicide treatments were necessary. The well struggled to keep up watering especially during the 2 weeks of dry weather in July, but soon had relief from rainfall. The field looked good all year and the yield was a little less than hoped for at 163 bu/acre.

The Drew County field was the last field planted on 22 May. The 34 acre field of clay soil was a challenge all year. With the late planting the variety of choice was CL XL 729 and the plant density was thin at 4 plants/ft^2. With cotton up on the west side and soybeans on the north the first herbicide application of Newpath was delayed 3 weeks. No pre-emergence herbicide had been applied and grass was already in the 4- to 5-leaf stage. Newpath and Strada herbicide were first applied followed by Ricestar and Newpath and we realized that we were still in a salvage situation. Regiment herbicide sold out, but we found one bag equivalent to a half rate. Internode elongation was only days away and Grasp herbicide was tank-mixed with Regiment and the grass was soon under control. We still, however, had some scattered sprangletop. Since the field was late planted and cleaned up late the yield had been affected and only yielded a disappointing 160 bu/acre.

The Jackson County field was planted early with CL XL 745 into a loose seedbed. The seed was a little deep, which should not have been a problem except for the rain, rain, and more rain. Part of the field was under water for a long time. The authors were beginning to get concerned as it took a long time for emergence. Stand counts indicated a uniform 4.5 plants/ft^2 which we decided was adequate; even the area under water recovered. It is amazing how the hybrid varieties have the ability to tiller and fill in. The field looked excellent the rest of the year. False smut was probably the worst in this field of all the fields for some reason, but the yield was still very good at 201 bu/acre.

The Jefferson County field was the only furrow-irrigated field in the program this year. The field was 41 acres with a clay soil. Roundup Power Max herbicide was used for burndown. The variety was CL XL 746 planted 26 April and emerged to a density of 12 plants/ft^2. Newpath, Facet, Command, and Permit were the standard herbicides used for contact and residual control and did a good job keeping the stale soybean beds weed free. The irrigation well went down for a short period, but was soon assisted by rainfall. Nitrogen loss is always a concern but the applications were excessive. No insecticides or fungicides were required in this field. After heading, sheath blight as well as false smut moved in swiftly. This field had severe shattering with an estimated 15- to 17-bu/acre on the ground. Harvest moisture was between 12% and 13% and the field yielded 172 bu/acre.

The Lawrence County field was the only zero grade field in the program this year. The same field was also in the program last year. The field was planted the first time on 25 April and then again nearly a month later. This field has trouble drying out in the spring and the water from other fields above it drains into it. When planted the first time, it was still wet and a big rain came just after planting and pushed the seed deep. Most of the seed rotted and hardly any came up. The re-plant decision was easy and the second stand was excellent. This field had low water use and the power unit ran very little after the second week in July. In fact, the flood was deep the entire season just from rainfall. The authors were really disappointed in the yield of 172 bu/acre. The rice was really uniform and looked to be a 200 bu/acre plus yield. Looks can be deceiving. The heads were small with a lot of vegetative growth. The only thing they authors can come up with is too much N was applied. The N rate was within our recommendations for a clay soil and rice following rice, however the rice appeared to have been over fertilized. The pre-flood N was applied with a spreader truck and was obviously applied much heavier around the outside of the field. It is a small triangle-shaped field and we are not sure how much was really applied. It looked like it got more than the recommended 300 lb/acre and the authors are still a little puzzled about it.

The Lee County field was seeded with Jupiter at a rate of 101 lb/acre. The stand density was 34 plants/ft^2. Phosphorus, K, and Zn fertilizer were applied according to the soil test results. Urea was applied at 240 lb/acre pre-flood followed by 100 lb/acre at mid-season. The herbicide applications include Command followed by Prowl, Permit, and Facet. The excessive rainfall helped the residual effect of the herbicides yet delayed fertilizer application resulting in an extra herbicide application of Ricestar. Stratego was used as a fungicide for early sheath blight control and false smut suppression. The Lee County field was the second highest yielding field in the 2009 Rice Research Verification Program at 214 bu/acre. Due to the high yield and the medium-grain premium the field economics were the highest in the program at $648/acre return above variable costs.

The Lincoln County field was 63 acres of clay soil. Roundup herbicide was used for as a burndown treatment. The chosen variety was CL XL 729 with a seeding rate of 30 lb/acre and was planted on 24 April. The stand density averaged 9 plants/ft^2 with the north end having a thinner stand. Ammonium sulfate and DAP were applied early while 175 lb/acre urea was applied at the pre-flood stage. The late boot application of urea was 70 lb/acre. The two standard applications of Newpath did a good job keeping the field weed free. Blazer herbicide was used later for control of coffeebean. The yield was a little disappointing at 170 bu/acre.

The Lonoke County field got off to a good start, but suffered damage from two hail storms. Significant yield loss occurred from the first storm just prior to heading. An additional application of urea was applied to try and promote some more growth. The second storm occurred after heading and caused minor shattering. The authors think the field would have been outstanding if it were not for the hail, but it still yielded 169 bu/acre.

Amazon sprangletop was the story in the Mississippi County field. Command was applied pre-emergence as we knew the field had a history of the weed. Even with the Command, it was still thick. Rice Star was added to the first Newpath application; however, the application was streaked and adequate control was not achieved. Clincher was applied and finally controlled the grass. The pre-flood urea application was also streaked from an air flow truck due to an equipment malfunction. The applicator provided an application of ammonium sulfate by air as a result. The rice headed in nice straight little rows across the field. Nitrogen delays maturity so the areas that were shorted-headed first. The yield was still excellent at 200 bu/acre.

In the Poinsett 1 County field the producer has been trying to increase the yield and has found that a lower seeding rate of Wells has provided positive results. This year the plan was to seed 50 lb/acre. Two planters were used and one was planting about 55 lb/acre and the other around 45 lb/acre. The difference in stand was evident, 45 lb was too low. The Command application controlled the grass for a long time and the authors thought we might be able to get by but there was some scattered red stem, smartweed, and other broadleaf weeds. Rainfall delayed the N application and some barnyardgrass did finally emerge. Propanil and Facet stopped controlling barnyardgrass in a while ago and we decided the situation would be perfect for Regiment. The Regiment was applied pre-flood but, as it turned out, we wished we had not applied it. The rice, especially in the thinner stand, was stunted for more than 3 weeks. The roots were pruned, not severely, and recovered pretty quickly. The rice just sat there and did not grow. The authors think it was the combination of cool weather, poor growing conditions, and especially the thin stand because the double-drilled areas of the field did not seem to be affected nearly as bad. The result was a disappointing 158 bu/acre. This field was treated with propiconazole in the boot stage for control of kernel smut as the field has a history of the disease. The field was also ringed with Quadris for control of sheath blight.

The Poinsett County 2 field was seeded in Jupiter and the weed control situation was similar to Poinsett County 1. Command controlled the grass for several weeks and Regiment was also applied pre-flood. The rice was also stunted for several weeks, especially in the areas with a thin stand. The yield in this field was also disappointing with 155 bu/acre.

The Prairie 1 County field was seeded in Jupiter. In part of the field, the previous crop was rice, the other part soybeans. The field was seeded no-till into the existing stubble. It started raining soon after the field was planted and this field was flooded for a long time early and it took a long time to get a stand. The producer pumped water off the field for a couple of weeks and was about ready to give up on it. The rice did finally emerge, but was very thin in some of the low areas due to all of the rain. Command did not get applied pre-emergence and the agent and and authors decided this would be an excellent field to test some of the new RiceCo herbicides tank-mixed with Command. The field was divided into 30-acre strips and the following treatments were applied: RicePro + Command, RiceBeau + Command, SuperWham + Command, and SuperWham + Facet. The authors never could tell much difference in the treatments, they all worked great. Coffeebean was worse in the RiceBeau treated area, but that may have just been where they were. A flush of barnyardgrass came up late as the flood was delayed due to all the rain. Regiment was also used in this field pre-flood, and again, severe stunting and slow growth occurred. The yield was a disappointing 159 bu/acre. The authors are convinced that, for whatever reason, the herbicide caused some yield loss in the three fields it was used in. It has never been documented in research but we have never had a year like this one either.

Prairie 2 County was an 88-acre field of silt loam soil. The chosen variety was Cheniere with a seeding rate of 90 lb/acre. Cruiser seed treatment was used due to a past history of grape colapsis and the field was planted on 25 April and emerged to a stand density of 22 plants/ft^2. Preplant fertilizer was applied according to soil test results and 320 lb/acre 18-60-90 plus 10 lb/acre Zn were applied by custom application. Ammonium sulfate was applied at 100 lb/acre with 50 lb/acre urea followed by 125 lb/acre urea. One hundred lb/acre of urea was applied at mid-season. Stratego fungicide and Karate insecticide were applied for disease control and stink bug control, respectively. The field yielded 188 bu/acre with a milling yield of 67/71.

The Randolph County field has been in rice for at least three consecutive years and has a history of red rice. The variety selected this year was CL 151. Facet was added to the first Newpath application to aid in control of barnyardgrass, coffeebean, and indigo. Following the second Newpath application, it was obvious a plane pass across the middle of the field was missed. Red rice was also present on the south end of the field. Beyond was applied in this area and killed most of the red rice. A small population of plants yellowed up but did not die and the authors are not sure if they were resistant, or just came up late and were missed with the Newpath. The field was clean overall. Sheath blight was very aggressive in this field and a fungicide application was made for control. The authors expected to find blast in this field, but never did. The field yielded 168 bu/acre, which was actually pretty good for this field and variety.

The White County field was a big field, 91 acres, with a hill side on one end stacked with levees. The field was irrigated from a reservoir but it still took 2 weeks to completely flood. The field was planted on 22 May which makes it one of the last fields planted. The variety was CL XL729 treated with Cruiser. The emergence was very fast and uniform. The rice came out of the ground growing and never looked back. Two applications of Newpath is all it took to keep the field clean and the authors were impressed with how the rice looked all year, even with the delay from the cool weather. To be honest, we did not expect the field to make 185 bu/acre because it was late planted, hard to water, and on a thin soil. Anyway, we did something right, and this was probably the highest yield ever made on this field.

On-Farm Research

Research was conducted in three of the verification fields in 2009. Disease monitoring tests were planted in Lincoln and Desha Counties. A herbicide trial was done in Prairie 1 County. The trial consisted of the post-emergence herbicides RicePro, RiceBeau, and Superwham tank-mixed with Command and applied in the 2- to 3-leaf stage.

SIGNIFICANCE OF FINDINGS

Data collected from the 2009 RRVP reflect the general trend of increasing rice yields and above-average returns in the 2009 growing season. Analysis of this data showed that the average yield was higher in the RRVP compared to the state average and the cost of production was equal to or less than the Cooperative Extension Service-estimated rice-production costs.

ACKNOWLEDGMENTS

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Table 1. Variety, soil series, previous crop, acreage, grain yield, milling yield, and harvest moisture for the 2009 Rice Research Verification Program by county.

County	Variety	Soil series	Previous crop	Acres	Grain yield	Milling yield[z]	Harvest moisture
					(bu/acre)		(%)
Arkansas	XL 723	Dewitt silt loam	Soybean	42	42	59/70	19
Ashley	CL XL 729	Perry clay	Soybean	44	44	55/67	16
Chicot	CL XL 729	Perry clay	Soybean	41	41	57/70	13
Clark	CL XL 745	Gurdon silt loam	Corn	72	72	56/70	17
Clay	CL XL 745	Amagon silt loam	Soybean	56	56	66/72	19
Crittenden	Wells	Sharkey silty clay	Rice	87	87	55/72	16
Cross	Jupiter	Henry silt loam	Soybean	41	41	64/69	17
Desha	Wells	Desha clay	Soybean	43	43	57/65	18
Drew	CL XL 729	Herbert silt loam	Soybean	34	34	50/66	20
Jackson	CL XL 745	Foley-Calhoun	Soybean	36	36	68/70	19
Jefferson	CL XL 746	Portland clay	Soybean	41	41	61/69	13
Lawrence	CL XL 729	Crowley silt loam	Rice	25	25	64/72	15
Lee	Jupiter	Calloway silt loam	Soybean	72	72	68/72	17
Lincoln	CL XL 729	Herbert silt loam	Soybean	63	63	59/70	17
Lonoke	CL XL 729	Loring silt loam	Soybean	32	32	58/65	17
Mississippi	CL XL 745	Sharkey-Steele	Rice	57	57	62/73	19
Poinsett 1	Wells	Henry silt loam	Soybean	77	77	69/73	18
Poinsett 2	Jupiter	Henry silt loam	Soybean	50	50	62/65	18
Prairie 1	Jupiter	Kobel silty clay	Soybean	112	112	67/71	18
Prairie 2	Cheniere	Calloway silt loam	Soybean	88	88	67/72	18
Randolph	CL 151	Dundee silt loam	Rice	79	79	61/70	17
White	CL XL 729	Loring silt loam	Soybean	91	91	57/71	20
Average				58	180	61/70	17

[z] Head rice / total white rice.

Table 2. Stand density, irrigation, seeding rate, and important dates in the 2009 Rice Research Verification Program season by county.

County	Stand density	Rainfall	Irrigation[z]	Rainfall + Irrigation	Seeding rate	Planting date	Emergence date	Harvest date
	(plants/ft^2)	(inches)	(acre in.)	(inches)	(lb/acre)			
Arkansas	14	28	26	54	30	23 Apr	1 May	7 Sep
Ashley	10	15	38	53	40	1 May	14 May	10 Oct
Chicot	9	18	26	44	33	23 Apr	7 May	28 Sep
Clark	8	39	26	65	47	26 April	11 May	20 Sep
Clay	8	14	16	30	31	22 May	31 May	19 Oct
Crittenden	18	24	24	48	100	27 Apr	13 May	20 Oct
Cross	20	27	26	53	74	7 Apr	26 Apr	12 Sep
Desha	18	23	18	41	123	22 Apr	14 May	22 Sep
Drew	4	16	26	42	30	22 May	4 June	20 Oct
Jackson	5	35	38	73	30	7 Apr	27 Apr	6 Sep
Jefferson	12	25	14	39	30	26 Apr	10 May	1 Oct
Lawrence	8	14	15	29	30	20 May	31 May	21 Oct
Lee	34	31	46	77	101	9 Apr	17 Apr	23 Sep
Lincoln	9	27	33	60	30	24 Apr	1 May	21 Sep
Lonoke	13	33	33	66	35	10 Apr	26 Apr	22 Aug
Mississippi	9	27	23	50	30	27 Apr	12 May	12 Sep
Poinsett 1	11	32	26	58	50	26 Apr	13 May	26 Sep
Poinsett 2	16	34	18	52	80	25 Apr	10 May	28 Sep
Prairie 1	11	30	26	56	86	26 Apr	4 May	28 Sep
Prairie 2	22	39	30	69	90	25 Apr	8 May	16 Sep
Randolph	19	25	26	51	67	27 Apr	12 May	22 Sep
White	9	22	26	48	32	22 May	30 May	17 Oct
Average	13	26	26	53	55	27 Apr	10 May	26 Sep

[z] The average of 25 acre-inches was used for fields not utilizing flow meters.

Table 3. Soil test results from 2009 Rice Research Verification Program fields and fertility recommendations.

		Soil test^{z}			Split application rates	Total-N	Preplant fertility
County	pH	P	K	Zn	of urea (45%)^{y}	rate	N-P-K-Zn^{x}
		----------	----------	----------	(lb/acre)	----------	----------
Arkansas	6.1	48	266	16.0	200-0-70	122	0-0-0-.25
Ashley	5.8	58	639	13.5	270-0-100	167	0-0-0-.25
Chicot	6.4	58	630	10.1	200-0-70	143	21-0-0-.25-24^{w}
Clark	5.4	40	120	6.3	270-0-70	192	39-86-60-.25-24^{w}
Clay	6.2	40	172	11.3	265-0-70	151	0-30-90-.25
Crittenden	5.3	72	185	3.5	250-100-0	179	21-0-30-.5-24^{w}
Cross	8.1	89	114	3.2	250-100-50	180	0-46-90-13
Desha	7.7	53	589	8.6	200-100-0	153	18-46-0-.5
Drew	5.8	26	740	10.0	200-0-75	124	0-0-0-.25
Jackson	6.8	52	250	6.2	240-0-75	160	18-46-60-.25
Jefferson	7.2	44	497	7.6	200-100-100	230	50-46-0-.25-36^{w}
Lawrence	6.1	38	210	16.0	300-0-70	167	0-30-60-.25
Lee	7.2	30	146	6.8	240-100-0	153	0-60-90-10
Lincoln	6.9	59	515	7.1	175-0-70	150	39-46-0-.25-24^{w}
Lonoke	6.6	64	234	6.2	200-75-100	190	21-30-60-.25-24^{w}
Mississippi	7.0	82	358	9.2	300-21-70	176	0-0-0-.25
Poinsett 1	6.3	40	212	29.7	260-100-0	183	21-30-60-0-24^{w}
Poinsett 2	7.4	48	166	27.5	230-100-0	149	0-60-90-0
Prairie 1	6.0	43	295	7.2	300-100-0	198	18-46-0-0
Prairie 2	7.2	45	136	28.0	200-100-0	153	18-60-90-10
Randolph	5.7	35	207	4.4	230-100-0	149	0-60-60-0
White	5.5	47	231	8.3	200-0-70	122	0-80-70-.25

[z] P= phosphorus, K=potassium, and Zn=zinc.

[y] Preflood-midseason-boot.

[x] N-P_2O_5-K_2O-Zn includes seed treatments.

[w] Ammonium sulfate was applied to 2- to 3-leaf rice and the field flush-irrigated.

Table 4. Selected variable input expenses from 2009 Rice Research Verification Program fields by county.[z]

County	Variety	Seed[y]	Fertilizer[x]	Herbicides[x]	Fungicides[x]	Insecticides[x]	Fuel[w]	Irrigation[v]
		----------------------------------	-------------------------------	[Input cost ($)/acre]	-------------------------------	-------------------------------	-------------------------------	----------------------------------
Arkansas	XL723	106.88	187.34	98.99	0.00	0.00	17.63	35.09
Ashley	CLXL729	168.00	103.78	100.87	0.00	11.44	20.60	95.18
Chicot	CLXL729	146.58	101.49	106.22	0.00	11.44	19.94	69.76
Clark	CLXL745	155.24	221.41	74.21	0.00	12.99	22.68	40.11
Clay	CLXL745	150.86	186.91	53.74	0.00	0.00	17.50	44.70
Crittenden	Wells	42.93	152.36	116.84	29.64	0.00	16.12	61.50
Cross	Jupiter	47.91	235.83	80.34	20.74	0.00	16.09	77.31
Desha	Wells	39.90	116.90	59.03	0.00	0.00	17.58	48.81
Drew	CLXL729	126.00	78.89	124.43	0.00	0.00	17.78	63.14
Jackson	CLXL745	157.40	163.77	70.25	0.00	0.00	27.10	96.49
Jefferson	CLXL746	146.00	204.96	118.68	0.00	0.00	10.40	39.08
Lawrence	CLXL729	126.00	152.31	66.18	0.00	0.00	12.76	34.54
Lee	Jupiter	52.30	194.42	76.55	29.64	0.00	21.09	113.79
Lincoln	CLXL729	133.98	127.22	72.46	0.00	0.00	18.59	49.12
Lonoke	CLXL729	158.27	252.52	67.43	0.00	0.00	15.06	77.92
Mississippi	CLXL745	146.00	90.38	107.74	0.00	0.00	18.58	59.98
Poinsett 1	Wells	19.47	187.30	56.76	20.40	0.00	11.72	34.11
Poinsett 2	Jupiter	24.03	189.93	48.46	0.00	0.00	23.67	43.85
Prairie 1	Jupiter	25.65	152.15	97.75	0.00	4.16	15.60	64.11
Prairie 2	Cheniere	41.13	206.00	52.73	26.39	8.19	23.02	56.63
Randolph	CLXL151	47.88	178.09	63.68	27.21	0.00	18.23	36.06
White	CLXL729	150.34	143.57	57.92	0.00	0.00	25.47	49.40
Weighted average 2009[u]		90.62	166.18	79.22	9.05	2.41	18.76	57.79
Weighted average 2008[t]		65.83	203.48	83.14	10.23	7.48	35.34	108.78
Change[s]		24.79	-37.30	-3.92	-1.18	-5.07	-16.58	-50.99

[z] Does not include all variable costs, such as drying, hauling, equipment repair, etc.

[y] Includes seed cost and treatments.

[x] Includes the cost of material and application for each input.

[w] Fuel for tractors, combines, and self-propelled equipment ($2.00/gal).

[v] Includes irrigation labor, irrigation supplies (levee gates & poly-pipe), irrigation repair and maintenance, and diesel fuel ($2.00/gal).

[u] Weighted by acres.

[t] Average costs from 2008 RRVP Fields using 2008 costs of production.

[s] Change in average costs from 2008 to 2009.

Table 5. Herbicide rates and timings for 2009 Rice Research Verification Program fields by county.[z]

Arkansas	**PRE**[y]: Command (12.8 oz) **POST**[x]: Facet (0.33 lb) Prowl (2.1 pt) fb RicePro (4 qt) Permit (0.5 oz)
Ashley	**PRE**: Command (25.6 oz) **POST**: Newpath (4 oz) Facet (0.33 lb) fb Newpath (4 oz) Aim (1 oz) fb Aim (0.5 oz)
Chicot	**PRE**: Newpath (4 oz) **POST**: Newpath (4 oz) Facet (0.33 lb) fb Facet (0.5 lb) Aim (0.5 oz)
Clark	**POST**: Newpath (4 oz) Facet (0.5 lb) fb Newpath (4 oz)
Clay	**PRE**: Command (13 oz) **POST**: Newpath (4 oz) Permit (0.33 oz) fb Newpath (4 oz)
Crittenden	**PRE**: Glyphosate (1 qt) Facet (0.5 lb) Prowl (2.4 pt) **POST**: Propanil (4 qt) fb Ricestar (17 oz)
Cross	**PRE**: Glyphosate (2 pt) Command (12.8 oz) **POST**: Propanil (2 qt) Facet (0.25 lb) Permit (0.5 oz)
Desha	**PRE**: Command (16 oz) **POST**: RicePro (4 qt)
Drew	**POST**: Newpath (4 oz) Strada (2 oz) fb Newpath (4 oz) Ricestar (24 oz) fb Grasp (2.3 oz) Regiment (0.22 oz)
Jackson	**POST**: Newpath (4 oz) Facet (0.5 lb) fb Newpath (4 oz)
Jefferson	**PRE**: Glyphosate (1.3 pt) **POST**: Facet (0.33 lb) Command (16 oz) fb Ultra Blazer (12.8 oz)
Lawrence	**PRE**: Glyphosate (1 qt) Command (13 oz) **POST**: Newpath (4 oz) fb Newpath (4 oz) Grandstand (10.5 oz) Propanil (1 qt)
Lee	**PRE**: Command (12.8 oz) **POST**: Prowl (2.1 pt) Permit (0.5 oz) Facet (0.25 lb) fb Ricestar (17 oz)
Lincoln	**PRE**: Glyphosate (1.5 pt) **POST**: Newpath (4 oz) fb Newpath (4 oz) fb Ultra Blazer (16 oz)
Lonoke	**PRE**: Command (12.8 oz) **POST**: Newpath (4 oz) fb Newpath (4 oz) Permit (0.33 oz)
Mississippi	**PRE**: Command (20 oz) **POST**: Newpath (4 oz) Ricestar (20 oz) fb Newpath (4 oz) Permit (0.5 oz) fb Clincher (15 oz)
Poinsett 1	**PRE**: Glyphosate (1 qt) Command (12.8 oz) Aim (0.8 oz) **POST**: Regiment (0.5 oz)
Poinsett 2	**PRE**: Command (12.8 oz) **POST**: Regiment (0.6 oz)
Prairie 1	**PRE**: Glyphosate (1 qt) **POST**: Propanil (4 qt) Command (16 oz) fb Regiment (0.5 oz)
Prairie 2	**PRE**: Command (12.8 oz)) **POST**: RiceBeau (4 qt)
Randolph	**POST**: Newpath (4 oz) Facet (0.25 lb) fb Newpath (4 oz)
White	**PRE**: Command (10 oz) **POST**: Newpath (4 oz) fb Newpath (4 oz)

[z] All rates are on a per-acre basis.

[y] **PRE** = pre-emergence.

[x] **POST**=post-emergence.

Table 6. Fungicide and insecticide applications in 2009 Rice Research Verification Program fields by county.

County	Sheath blight	Blast	Rice water weevil	Rice stink bug
Arkansas	------	------	------	------
Ashley	------	------	------	Karate (1.6 oz)
Chicot	------	-----	------	Karate (1.6 oz)
Clark	------	------	------	Karate (2.1 oz)
Clay	------	------	------	------
Crittenden	------	Stratego (19 oz)	------	------
Cross	Quadris (6.5 oz)	------	------	------
Desha	------	------	------	------
Drew	------	------	------	------
Jackson	------	------	------	------
Jefferson	------	------	------	------
Lawrence	------	------	------	------
Lee	Stratego (19 oz)	------	------	------
Lincoln	------	------	------	------
Lonoke	------	------	------	------
Mississippi	------	------	------	------
Poinsett 1	------	------	------	------
Poinsett 2	------	------	------	------
Prairie 1	------	------	Mustang Max (3.2 oz)	------
Prairie 2	Stratego (19 oz)	------	------	Karate (1.6 oz)
Randolph	Stratego (17 oz)	------	------	------
White	------	------	------	------

Table 7. Economic analysis of fields from 2009 RRVP by county.^{z}

County	Yield	Milling yield	Crop price^y	Specified variable costs^x	Specified ownership costs^w	Land costs^v	Return above variable costs	Return above total costs	BEP^u to equal variable costs	BEP to equal total costs	Milling yield premium or discount^t
	(bu/acre)		($/bu)	($/acre)					($/bu)		($/acre)
Arkansas	192	59/70	5.80	597	27	180	312	285	3.77	3.97	20.05
Ashley	201	55/67	5.52	662	56	170	246	190	3.98	4.38	-36.73
Chicot	216	57/70	5.75	624	54	203	390	336	3.50	3.83	11.28
Clark	193	56/70	5.73	691	62	173	211	149	4.36	4.79	5.04
Clay	209	66/72	6.11	619	57	212	421	364	3.59	3.95	85.48
Crittenden	145	55/72	5.82	542	52	129	148	97	4.54	5.03	17.67
Cross	203	64/69	7.21	641	53	248	550	496	3.83	4.19	43.39
Desha	163	57/65	5.45	413	52	132	312	261	3.05	3.47	-41.14
Drew	160	50/66	5.33	542	53	124	156	103	4.11	4.55	-59.87
Jackson	201	68/70	6.04	688	78	196	304	226	4.15	4.67	68.22
Jefferson	172	61/69	5.80	651	36	154	162	126	4.62	4.90	16.46
Lawrence	172	64/72	6.06	524	45	168	324	279	3.70	4.05	61.37
Lee	214	68/72	7.57	671	62	270	648	586	3.78	4.19	121.21
Lincoln	170	59/70	5.80	541	55	151	264	209	3.87	4.29	17.75
Lonoke	169	58/65	5.47	717	50	142	41	-9	5.17	5.58	-38.24
Mississippi	200	62/73	6.07	582	56	199	407	351	3.52	3.90	73.10
Poinsett 1	158	69/73	6.25	452	40	157	354	313	3.45	3.80	86.62
Poinsett 2	155	62/65	6.85	466	66	172	398	332	3.64	4.20	-23.19
Prairie 1	159	67/71	7.46	490	51	196	475	425	3.72	4.16	73.07
Prairie 2	188	67/72	6.14	571	65	182	369	305	3.68	4.14	81.80
Randolph	168	61/70	5.86	509	55	156	294	239	3.67	4.11	26.32
White	185	57/71	5.81	585	71	173	293	222	3.83	4.34	20.93
Weighted average 2009	180	61/70	6.18	572	55	178	334	279	3.86	4.28	36.38

continued

Table 7. Continued.

County	Yield	Milling yield	Crop price[y]	Specified variable costs[x]	Specified ownership costs[w]	Land costs[v]	Return above variable costs	Return above total costs	BEP[u] to equal variable costs	BEP to equal total costs	Milling yield premium or discount[t]
	(bu/acre)		($/bu)	----------------------------------($/acre)------------------------------					----------($/bu)---------		($/acre)
Weighted average 2008	171	57/69	7.51	673	48	216	371	323	4.89	5.27	3.60
Change[s]	9	---	-1.13	-1.01	7	-38	-37	-44	-1.03	-0.99	32.78

[z] Twenty percent crop-share rent was assumed.

[y] Based upon premium or discount above $5.70/bu long-grain and $7.00/bu medium-grain with a standard milling of 55/70.

[x] Includes all variable expenses for production, drying, hauling, checkoff fee, interest, etc.

[w] Excludes ownership expenses of irrigation well, which are assumed to be paid by the landlord.

[v] Gross value of landlords 20% share of crop less drying charges, check-off fee, and irrigation fixed expenses.

[u] BEP = break-even price.

[t] Impact of milling on gross returns. (Gross returns with milling yields – gross returns at standard milling, i.e. 55/70).

[s] Changes in averages from 2008 to 2009.

BREEDING, GENETICS, AND PHYSIOLOGY

Molecular Characterization/Purification of a Working Germplasm Collection

V.A. Boyett, A.M. Stivers, and J.W. Gibbons

ABSTRACT

Since 2001, Rice Breeding and Genetics at the University of Arkansas Division of Agriculture Rice Research and Extension Center (UA RREC) has had a technical support project utilizing DNA marker analysis to aid in the genetic enhancement of rice germplasm, specifically in the areas of disease resistance and cooking quality. Simple sequence repeat (SSR) and single nucleotide polymorphism (SNP) markers linked to these specific traits are used to predict the cooking quality of milled grain and screen for the presence of rice blast [*Magnaportha grisea* (T.T. Hebert) M.E. Barr] resistance genes. More than 90% of the project's effort each year is devoted to Marker-Assisted Selection (MAS) screening of early generation segregating populations with these trait-linked markers, increasing the efficiency of selection of progeny with desired characteristics that has the potential for commercial success. Since the program's inception, major emphasis has been placed on using these markers to genotype the bank of elite breeding material used as parents for these populations. Characterizing this Working Germplasm Collection (WC) on a molecular level enables the determination of which populations would benefit from MAS, purification of the entries, and more efficient design of cross combinations to introgress desired traits. Molecular analysis was performed on 307 entries of the WC for genes linked to rice blast disease resistance, amylose content, and plant height. In addition, MAS screening with the same markers was utilized to correlate genotype and phenotype and confirm purity of 45 WC accessions that were phenotypically purified in the field.

INTRODUCTION

In any plant breeding program, its foundation is its collection of elite breeding lines, and it is important that it be extensively characterized so that the breeder can improve chances of success in developing lines for commercial release. Each year, the WC receives 30 to 40 new entries, so the characterization is a continuous endeavor. The collection is meticulously evaluated for approximately 40 phenotypic traits (IBPGR-IRRI, 1980). Based upon this evaluation process, 45 entries of the WC were determined to be segregating for one or more of these traits and in need of purification before further use in the breeding program.

In addition to the phenotypic characterization, genotyping this WC gives the breeder more information regarding the genetic background, diversity, and potential of the parental material. In an effort to "deepen the gene pool" or widen the germplasm base, and identify new resources of desirable traits, many entries in the WC are of diverse origin, and frequently possess agronomic traits that are undesirable. Using MAS to eliminate those lines with undesirable traits means that only lines with the highest probability of acceptance will be advanced to large plots in later generations, thus saving valuable and limited land area in Stuttgart and Puerto Rico for the best material.

Molecular markers for screening were chosen on the basis that they were not only informative markers that are in routine use for MAS in the program, but also that they were linked to rice blast disease resistance, cooking quality, and plant height genes that would significantly impact phenotype.

The objectives of this continuous study are to (i) increase the efficiency of applying MAS to the crosses made by the breeding program at the UA RREC, thus improving the chances for success in the development of new lines for commercial release, (ii) determine the haplotype of the entries of the WC at the loci for important agronomic traits, and (iii) strive to ensure purity and a correlation between genotype and phenotype of the entries of the WC.

PROCEDURES

All entries of the WC were tested, initially by screening two bulked seed samples of 10 seeds each for a total of 20 seeds for each entry. For the initial screening, dehulled seed was placed into 2-ml ScrewCap Mictrotubes along with about 20 1-mm glass beads, processed in a BeadBeater-96 (BioSpec Products, Bartlesville, Okla.), and DNA was extracted using a sodium hydroxide based method.

Criteria for a heterozygous score were that the smaller peak had to be at least 20% of the taller peak and the sample had to have a genotyping quality (GQ) score of at least 0.4 units. Close alleles were scored manually. Any entry amplifying more than one allele at a given locus was further screened as a leaf sample from an individual plant so that the difference between heterozygous individuals and seed mixtures could be determined. Data anomalies and suspected cross-contaminated samples were repeated for confirmations and correction, at least from the polymerase chain reaction (PCR) step. In some cases new DNA samples were extracted and the marker analysis repeated.

There were 45 WC accessions in need of purification based on phenotypic evaluation and these were planted in rows of 10 plants each in a separate Phenotype observation bay (PB). Each individual plant was assigned a number and the tissue sample collected into a separate envelope so that the marker analysis data could be traced to the exact plant from which the leaf tissue sample was taken. After phenotype evaluation, molecular analysis, and comparison of descriptors in the Germplasm Resource Information Network (GRIN) (http://www.ars-grin.gov/npgs/searchgrin.html), each row in the PB was purified of off-types and desired plants allowed to mature for seed increase.

Leaf tissue was harvested into manila coin envelopes and stored at -80 ºC until sampled with a single hole-punch. DNA was extracted using Sodium hydroxide/Tween 20 and neutralized with 100mM Tris-HCl, 2mM EDTA. The DNA samples were arrayed in a 96-well format and 2 µl of template used for each 25 µl PCR analysis.

Markers chosen were RM208 linked to *Pi-b* resistance; YL155, YL183, and Pi-indica for the rice blast resistance gene *Pi-ta*; and AP5659-1 for *Pi-z* resistance (Fjellstrom et al., 2004, 2006; Jia et al., 2004). A “Null” allele with the AP5659-1 marker was confirmed with additional PCR at AP5659-5 (Fjellstrom et al., 2006). *Waxy*, a gene influencing amylose content of the mature grain was evaluated with RM190 (Bergman et al., 2001), and RM1339 was used to screen for *sd1*, the most common gene to determine semidwarf plant height (GRAMENE, Sharma et al., 2009).

PCR was performed with either HEX or FAM labeled primers by adding template and enough bovine serum albumin and polyvinylpyrrolidone 40 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.). Resulting PCR products were grouped according to allele sizes and dye colors and diluted together with an epMotion 5070 liquid handling robot, also from Eppendorf North America. The amplicons were resolved with an Applied Biosystems 3730 DNA Analyzer, and analyzed using GeneMapper software (Applied Biosystems, Foster City, Calif.).

RESULTS AND DISCUSSION

Of the 307 accessions, the PCR analysis was repeated on 84 to confirm heterozygous scores, investigate reaction failure scores in GeneMapper, and increase amplification of those samples with GQ below 0.4 units and therefore not trustworthy. Leaf tissue samples were collected from individual plants to confirm heterozygotes or seed mixtures in the case of 63 entries. After analysis of individual plant samples 43 entries were determined to be problematic, segregating at one or more loci tested. (Table 1)

Of the 45 entries in the PB, 26 were segregating by genotype (Table 1), and four were random off-types. The remaining 15 entries appeared homozygous and uniform with the markers used. Evidently, these entries were segregating for traits for which no markers were used.

SIGNIFICANCE OF FINDINGS

Molecular characterization of the WC explained the incidence of non-parental alleles being amplified in MAS projects involving crosses made prior to the use of DNA marker analysis in the breeding program at the UA RREC, and some of the phenotypic segregation observed in the Crossing Block planted each year to serve as parental material for crosses. The genotyping enabled rapid determination of which crosses would benefit from MAS screening of early generation progeny. In addition, the data identified the genetic profile at the five loci linked to rice blast disease resistance, cooking quality, and plant height of each WC entry and assisted in determining which entries needed purification, or, in the case of four entries, replacement. The entries of the PB were selected because of observed phenotypic segregation, yet 26 of the 45 entries were also segregating on a molecular level for these important agronomical traits.

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Table 1. WC and Phenotype Bay entries segregating at five loci tested. (Some entries were segregating at multiple loci.)

	Pi-ta	*Pi-b*	*Pi-z*	*Waxy*	*sd1*
(no. of entries)					
WC (307 total)	13	14	13	24	11
PB (45 total)	17	11	9	14	10

BREEDING, GENETICS, AND PHYSIOLOGY

Development of Semidwarf Long- and Medium-Grain Cultivars

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ABSTRACT

Semidwarf rice cultivars contribute to the continued success of Arkansas rice production. Experimental semidwarf lines are in all stages of development from segregating populations to breeder head rows. New sources of yield, disease, and stress resistance are being used as parents in the breeding program, and techniques such as molecular aided selection are utilized to efficiently identify disease and quality genes in segregating populations. Lines with diverse genetic origins exhibit high yields, good disease and stress tolerance, and acceptable grain quality under Arkansas growing conditions. Continued exchange and utilization of new germplasm is valuable to Arkansas rice improvement.

INTRODUCTION

Since the release of ‘Lemont’ in the mid 1980s, semidwarf rice cultivars have been grown in Arkansas. ‘Cocodrie’, and ‘Bengal’ are long- and medium-grain semidwarfs that have occupied a large proportion of the rice area. These cultivars continue to be the base for semidwarf cultivar development in Arkansas. Recently, the first semidwarf long- and medium-grain cultivars ’Cybonnet’ and ‘Medark’ were released by the University of Arkansas Division of Agriculture, Agricultural Experiment Station (Gibbons, et al., 2006).

Lee et al. (1998) have characterized several recently introduced USDA germplasm accessions as tolerant to both rice sheath blight [*Rhizoctonia solani* (Kuhn)] and blast

[*Magnaportha grisea* (T.T. Hebert) M.E. Barr]. Most of these introductions belong to the indica subtribe of cultivated rice. Indicas have been suggested as sources for yield potential and disease resistance for domestic breeding programs (Eizenga, et al., 2006). Our objective is to develop genetically diverse semidwarf long- and medium-grain cultivars that are high yielding with excellent grain, milling and processing qualities that tolerate the common stresses and pests found in Arkansas rice fields.

PROCEDURES

Potential parents for the breeding program are evaluated for the desired objectives. Cross combinations are programmed that combine desired characteristics to fulfill the breeding objectives. Use of parents of diverse genetic backgrounds is emphasized. Segregating populations are planted at Stuttgart and the winter nursery at Lajas, Puerto Rico. Selection is based on grain and plant type, spikelet fertility, field and greenhouse disease reaction, and grain quality. Yield evaluations include the preliminary yield trial (PYT) and the Stuttgart Initial Test (SIT) at two locations, the University of Arkansas Division of Agriculture Rice Research and Extension Center (RB) at Stuttgart and the University of Arkansas Division of Agriculture Rohwer Research Station (SE) at Rohwer; the Arkansas rice performance trials (ARPT) at six locations in the state including two locations in producers fields; and the Uniform Regional Rice Nursery (URRN) conducted in cooperation with rice breeding programs in Texas, Louisiana, Missouri, and Mississippi. As in the past few years, the preliminary yield trial and SIT also were planted at the Pine Tree Experiment Station under high natural disease pressure using blast “spreader rows”.

RESULTS AND DISCUSSION

About 308 cross combinations were made in 2009 of which 34% were single and 66% were triple crosses. About 20% were medium-grain, 12% aromatic, and the remainder long-grain crosses. Emphasis was placed on triple crosses with parents selected for tolerance to the physiological disorder straighthead, blast, and panicle blight disease as well as field yield and grain quality. Over 970 F_1 single plants from triple crosses were selected in 2009 and will be space planted at Stuttgart in 2010 (Table 1). Over 4200 F_2 single plants were selected during the year. Several of these crosses were programmed with cold tolerant parents and, as in preceding years, the populations were exposed to cool temperatures in the field. Panicles from these plants were sent to the winter nursery for generation advancement. We were able to advance a portion of these for two generations in Puerto Rico this year. Plants with known sources of blast genes *Pi-ta*, *Pi-z, and Pi-b,* and diverse cooking quality alleles were evaluated using molecular aided selection (MAS) allowing for significant increase in efficiency of selection at Puerto Rico. At Stuttgart, panicles from over 250 F_3 rows were selected to advance to F_5 at Puerto Rico. Also, from over1400 rows planted, about 65 F_5 lines were selected based on plant type, grain quality, earliness, and disease reaction to advance to preliminary yield trials.

Yields of selected semidwarf lines from the preliminary yield trial are shown in Table 2. The experimental line 1318 from the cross CYBT/PI 560247//RU0301099 was the highest yielding cultivar at RB and also recorded the highest yield at SE with an 11% combined yield advantage over the check, ‘Wells’. Entry 1318 milled well and had low scores for blast and straighthead. Two medium-grains (Entries 1199 and 1308) highlighted in Table 2 had numerically higher average yields than the checks across both locations, and better disease scores. The other two medium-grains, 1263 and 1265, had higher yields than the medium-grain checks at Stuttgart but not at SE, but had better disease scores than the checks and acceptable milling yields. Several entries in the PYT had large panicle size and good early vigor (data not shown) indicating that selection for these traits is effective in early generations. Superior lines selected from the PYT will be advanced to the 2010 SIT and ARPT. All the experimental lines are semidwarf but variation in plant height was observed. The use of blast spreader rows at Pine Tree to simultaneously evaluate for disease and agronomic traits continues to be successful. Plant growth was very good under the disease system and blast disease pressure was good enough to identify susceptible lines. In 2010 more experimental lines, including selected F2 populations, will be tested under similar conditions at Pine Tree.

Data for nine semidwarf experimental lines and check cultivars from the semidwarf Stuttgart Initial Test (SIT) for 2009 are shown in Table 3. At RB, yields varied from 198 to 162 bu/acre with all entries except 2025 and the check ‘Bengal’ producing yields significantly the same as the check cultivar, Wells. At SE, yields varied from 181 to 112 bu/acre. The very frequent and heavy rains of 2009 resulted in a delayed harvest at SE which negatively affected grain yields at that location. The long-grain Entry 2089 had stable yields across locations and produced significantly higher yield than the Cybonnet check at SE. Milling also was equal to Cybonnet with good disease scores. The other long-grain entries performed numerically better at RB than SE but all had good disease scores and acceptable milling. The medium-grain Entry 2075 had a numerically higher yield than the check Bengal at RB, but significantly lower yield at SE. Grain size as indicated by kernel weight, and disease scores, however, were superior to Bengal. We are testing our material for “delayed harvest” milling effect and have identified sources for tolerance(data not shown). Identification and incorporation of parents with disease tolerance and diverse genetic backgrounds, while maintaining grain quality and yield in the progeny will continue to be a priority. The continued exchange and use of new germplasm is an important component of this project. Seven of the eleven highlighted entries from this years’ PYT and SIT include parents from either Africa, South America, or China.

SIGNIFICANCE OF FINDINGS

Promising semidwarf experimental lines with diverse genetic backgrounds have been identified that have good disease resistance, high yields, and good milling quality. Semidwarf long- and medium-grain rice varieties offer producers options in their choice of cultivar 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. Number of early generation lines selected in project ARK02030 during 2009.

	Number of lines	
Evaluation phase	Planted	Selected
F_1 Transplants	5,365	974
F_2 Space plants	277,800	4,237
F_4 Panicle rows	1,400	250
F_5 & F_6 Panicle rows	1,400	65

Table 2. Data from the 2009 Semidwarf Preliminary Yield Trial (PYT) for selected experimental lines and check cultivars.

	Grain	Yield[z]			Disease[y]		50%				Milling[w]
Entry	type	RB	SE	avg.	NB	SH	HD[x]	Height	Vigor	Kernel wt.	HR:TOT
		------------(bu/acre) ------------						(in.)	(1-4)	(mg)	
1318[x]	L	204	183	194	2	2	91	38	3	18.6	63:70
1199	M	189	157	173	1	4	86	37	3	20.2	68:71
1308	M	166	171	168	1	3	92	33	3	24.6	66:72
1263	M	190	129	160	1	3	88	35	3	24.4	68:74
1265	M	174	96	135	1	4	86	34	3	21.0	65:71
Wells	L	196	154	175	9	6	92	41	3	ND	ND
Medark	M	158	159	158	8	6	84	35	3	ND	ND
Bengal	M	165	158	162	9	7	85	36	4	ND	ND

[z] The 2009 PYT consisted of one replication at two locations, the Rohwer Research Station (SE), Rowher, Ark., and the Rice Research and Extension Center (RB) Stuttgart, Ark.

[y] Disease scores from field evaluation: Neck Blast (NB) at Pine Tree Experiment Station where 0 = no blast and 9 = heads dead and Straighthead (SH) from RB where 0 = no straighthead and 9 = complete sterility,

[x] Data for 50% heading date(HD), height, vigor, kernel weight, and milling are from RB. Vigor is on scale of 1 to 4 where 1 = low vigor and 4 = very vigorous.

[w] Entry 1318 is from the cross CYBT/PI 560247//RU0301099, Entry1199 is from the cross STG02PR-02-067/STG02AC-15-002//RU0401084, Entry 1308 is from RU0401084/IRAT 13//M-401, 1263 is from RU0401067/IRAT 13//STG03F5-04-062, and 1265 is from RU0401084/IRAT 13//STG03F5-04-062.

Table 3. Data from the 2009 Semidwarf Stuttgart Initial Test (SIT) for selected experimental lines and check cultivars.

	Grain	Yield[z]			Disease[y]		50%				Milling[w]
Entry	type	RB	SE	avg.	NB	SH	HD[x]	Height	Vigor	Kernel wt.	HR:TOT
		------------(bu/acre) ------------						(in.)	(1-4)	(mg)	
2089[w]	L	171	173	172	1	2	94	35	3	1.90	63:70
2090	L	181	156	168	0	1	91	36	3	1.85	58:69
2041	L	189	133	161	1	1	85	34	4	1.87	57:71
2075	M	186	114	150	2	4	93	37	4	2.30	66:70
2025	L	162	132	147	2	2	78	39	4	1.84	53:68
2086	L	177	112	144	2	1	96	38	3	1.90	64:71
Cybonnet	L	173	130	152	3	3	94	39	4	1.90	60:71
Bengal	M	162	181	172	9	7	87	33	4	1.90	65:73
Wells	L	198	168	183	9	6	94	41	4	1.80	62:72
LSD.05		36	39				3	5		0.24	8:2

[z] The 2009 SIT consisted of two replications at two locations, the Rohwer Research Station (SE), Rowher, Ark., and the Rice Research and Extension Center (RB) Stuttgart, Ark.

[y] Disease scores from field evaluation: Neck Blast (NB) at Pine Tree Experiment Station where 0 = no blast and 9 = heads dead and Straighthead (SH) from RB where 0 = no straighthead and 9 = complete sterility.

[x] Data for 50% heading date(HD), height, vigor, kernel weight, and milling are from RB. Vigor is on scale of 1 to 4 where 1 = low vigor and 4 = very vigorous.

[w] Entry 2089 is from the cross STG00F5-07-007/LM 1//CYBT, Entry 2090 is from the cross CYBT/LM 1, Entry 2041 is from CCDR/ZHE 733//IRGA 17, 2075 is from MDRK/PI312777//Jing 185-7, 2025 is from DREW/UA99-167, and 2086 is from CYBT/SABR.

BREEDING, GENETICS, AND PHYSIOLOGY

‘Roy J’, High Yielding, Stiff-Strawed, Long-Grain Rice Variety

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ABSTRACT

‘Roy J’ a new mid-season, high yielding, long-grain rice cultivar was derived from the cross ‘LaGrue’//’Katy’/’Starbonnet’/5/’Newbonnet’/Katy//RA73/’Lemont’/4/’Lebonnet’/9902/3/’Dawn’/9695//Starbonnet. Roy J was named for the late Roy J. Smith, a weed scientist with the USDA-ARS located at the University of Arkansas Division of Agriculture Rice Research and Experiment Center (RREC) from 1955 to 1993 when he retired. Roy J has been approved for release to qualified seed growers for the summer of 2010. The major advantage of the cultivar, released as Roy J is its high yield potential, stiff straw, and good milling yield. Roy J is a standard height long-grain rice cultivar similar to ‘Wells’ in appearance with very good lodging resistance. Roy J is susceptible to rice blast [*Magnaportha grisea* (T.T. Hebert) M.E. Barr] and straighthead, and moderately susceptible to sheath blight [*Rhizoctonia solani* (Kuhn)].

INTRODUCTION

Roy J was developed in the rice improvement program at the RREC near Stuttgart, Ark., and has been released to qualified seed growers for the 2010 growing season. Roy J has high rough-rice grain yield, good milling yield and very good lodging resistance. It is similar in maturity to ‘Drew’ and similar in height to LaGrue and ‘Taggart.’ Roy J was developed with the use of rice grower check-off funds distributed by the Arkansas Rice Research and Promotion Board.

PROCEDURES

Roy J rice (*Oryza sativa* L.), is a very high yielding, mid-season, long-grain rice cultivar developed by the University of Arkansas Division of Agriculture Agricultural Experiment Station. Roy J originated from the cross LaGrue//Katy/Starbonnet/5/Newbonnet/Katy//RA73/Lemont/4/Lebonnet/9902/3/Dawn/9695//Starbonnet (cross no.20001692), made at the RREC in 2000. 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. Newbonnet (Johnston et al., 1984) is a high yielding, excellent milling cultivar, susceptible to rice blast. RA73 is a selection from 'Bonnet 73' (Johnston et al., 1973) irradiated with a Fission Neutron rate of 1800 R (line # STG74MU429). Lemont is a long-grain semidwarf released by Bollich et al., 1985. Lebonnet, released in 1975 (Bollich et al., 1975), is a large kernel, long-grain rice cultivar. CI 9902 is a short stature, lodging resistant, rice blast resistant, long-grain selection developed at Crowley, and has the pedigree Dawn/245717/3/13-D//'Rexoro'/Unknown. Dawn is a blast resistant, long-grain gold-hulled cultivar widely used in crosses, which was described by Bollich et al., in 1968. CI9695 has the pedigree CI9453/CI9187//'Bluebonnet 50'. The experimental designation for early evaluation of RU0801076 was STG04L-37-098, starting with a bulk of F_6 seed from the 2004 panicle row L-37-098. RU0801076 was tested in the Arkansas Rice Performance Trials (ARPT) and the Cooperative Uniform Regional Rice Nursery (URRN) during 2007-2009 as entry RU0801076 (RU number indicated Cooperative Uniform Regional Rice Nursery; 08 indicates year entered was 2008; 01 indicates Stuttgart, Ark.; and 076 its entry number).

In 2007, the ARPT was conducted at five locations in Arkansas: RREC; Northeast Research and Extension Center, (NEREC), Keiser Ark.; Rohwer Research Station (SERRS), Rohwer, Ark.; a Clay County producer field, Corning Ark. (CCPF); and Jackson County producer field, Newport, Ark. (JCPF). In 2008 the ARPT was grown at the RREC, Pine Tree Experiment Station, (PTES), Colt, Ark.; NEREC, SERRS, and JCPF and in 2009 at RREC, PTES, NEREC, SERRS, and Cross County producer field, Wynn, Ark. (WCCPF). Each year the tests had three replications per location to reduce soil heterogeneity effects and to decrease the amount of experimental error. Roy J was also grown in URRN at RREC, Malden, Missouri; Crowley, Louisiana; Stoneville, Mississippi; and Beaumont, Texas from 2008 to 2009. Data collected from these tests included plant height, maturity, lodging, kernel weight, percent head rice, percent total rice and grain yield adjusted to 12% moisture and disease reaction information. Cultural practices varied somewhat among locations, but overall the trials were grown under conditions of high productivity as recommended by the University of Arkansas 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

Data, presented by year, are given in Table 1 for Roy J and other short- and mid-season cultivars grown in the ARPT. Rough rice grain yields of Roy J have consistently ranked as one of the highest in the Arkansas Rice Performance Trials (ARPT) being equal to or better than the yields of 'Francis', LaGrue, and Wells in all three years. In 15 ARPT tests (2007 to 2009), Roy J, Taggart, Francis, Wells, LaGrue, and 'Cybonnet', averaged yields of 196, 174, 173, 174, 166, and 161 bu/acre at 12% moisture, respectively. Data from the URRN (Table 2) conducted at Arkansas, Louisiana, Mississippi, Missouri, and Texas during 2008 to 2009, had the average grain yield of Roy J at 207 bu/acre at 12% moisture. This compared favorably with those of Taggart, Francis, Wells, and Cybonnet, at 214, 190, 196, and 188 bu/acre, respectively. Milling yields (percent whole kernel:percent total milled rice) at 12% moisture from the ARPT, 2007 to 2009, averaged 59:71, 58:72, 61:71, 55:72, 57:70, and 64:72, for Roy J, Taggart, Francis, Wells, LaGrue, and Cybonnet, respectively. Milling yields for the URRN, 2008 to 2009, averaged 58:72, 57:72, 59:71, 59:72, and 65:73, for Roy J, Taggart, Francis, Wells, and Cybonnet, respectively.

Roy J is similar in maturity to Taggart (Table 1). It has a stronger straw strength than Francis or Wells which is an indicator of lodging resistance. On a relative straw strength scale (0 = very strong straw, 9 = very weak straw) Roy J, Francis, Wells, LaGrue, Drew, Cybonnet, and 'Cocodrie' rated 2, 4, 3, 5, 6, 2, and 2, respectively. Roy J is 43 inches in plant height which is similar to Taggart and LaGrue (Tables 1 and 2).

Roy J, like Francis, Wells and LaGrue, is susceptible to common rice blast races IB-1, IB-33, IB-49, IC-17, IE-1, and IE-1K with summary ratings in greenhouse tests of 6, 7, 6, 1, 5, and 5, respectively, using the standard disease scale of 0 = immune, 9 = maximum disease susceptibility. Roy J is rated MS to sheath blight which compares with Francis (MS), Wells (S), LaGrue (MS), Cybonnet (VS), Cocodrie (S), and Drew (MS), using the standard disease R = resistant, MR = moderately resistant, MS = moderately susceptible, S = susceptible, and VS = very susceptible to disease. Roy J is rated S for kernel smut [*Tilletia barclayana* (Bref.) Sacc. & Syd. in Sacc.] which compares to Francis (VS), Wells (S), LaGrue (VS), Cybonnet (S), Cocodrie (S), and Drew (MS). Roy J is rated S to stem rot [*Sclerotium oryzae* (Catt.) R.A. Krause and R.K. Webster], R to brown spot [*Cochliobolus miyabeanus* (Ito & Kuribayashi in Ito) Drechs. ex Dastur], MR to narrow brown leaf spot (*Cercospora oryzae* Miyake), and S to false smut [*Ustilaginoidea virens* (Cooke) Takah].

According to 2008 and 2009 observations, like LaGrue, it is MS to sheath blight and crown (black) sheath rot (*Gacumannomyce graminis* var. *graminis*) and S to stem rot. Roy J is rated susceptible to bacterial panicle blight (*Burknoideria gluinae*). Roy J has a susceptible reaction to the physiological disorder straighthead and should be drained on the straighthead soils. Under high nitrogen fertilization, Roy J is susceptible to kernel smut and false smut.

Plants of Roy J have erect culms, dark 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. Roy J is partially awned with long awns on the lemma. Kernels of Roy J are similar in size to LaGrue, and Cybonnet. Individual milled kernel weights of Roy J, Taggart, Francis, Wells, LaGrue, Cybonnet, and Drew averaged 18.3, 20.2, 17.3, 18.9, 17.8, 17.7, and 15.9, respectively, in the ARPT, 2007-2008.

The endosperm of Roy J is nonglutinous, nonaromatic, and covered by a light brown pericarp. Rice quality parameters indicate that Roy J has typical southern U.S. long-grain rice cooking quality characteristics as described by Webb et al. 1985. Roy J has an average apparent starch amylose content of 22.4 g kg^{-1} and an intermediate gelatinization temperature (70 °C to 75 °C), as indicated by an average alkali (17 g kg^{-1} KOH) spreading reaction of 3 to 5.

SIGNIFICANCE OF FINDINGS

The release of Roy J provides producers with a high yielding, long-grain rice replacement for Wells or Francis. It has the benefit of having very good lodging resistance which is very desirable in a standard height cultivar.

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Table 1. Three year average agronomic data from the 2007 to 2009 Arkansas Rice Performance Trials for Roy J and other cultivars.

	Yield					50%	Kernel	Milling
Cultivar	2007	2008	2009	mean[z]	Height	Heading	wt.	HR:TOT[y]
	------------------(bu/acre) -----------------				(in.)	(days)	(mg)	
Roy J	215	186	187	196	43	96	18.3	59:71
Taggart	190	149	184	174	44	95	20.2	58:72
Francis	185	152	181	173	39	89	17.3	61:71
Wells	185	157	180	174	41	91	18.9	55:72
LaGrue	186	144	167	166	44	93	17.8	57:70
Cybonnet	171	158	155	161	36	91	17.7	64:72
Drew	175	136	165	159	44	94	15.9	59:71
C.V.$_{0.05}$	10.3	12.1						

[z] 2007 consisted of five locations, Rice Research and Extension Center, (RREC), Stuttgart, Ark.; Northeast Research and Extension Center, (NEREC), Keiser, Ark.; Rohwer Research Station (SERRS), Rohwer, Ark.; Clay County producer field (CCPF); and Jackson County producer field (JCPF); 2008: RREC, Pine Tree Experiment Station, (PTES),Colt, Ark; NEREC, SERRS, and JCPF; and 2009: RREC, PTES, NEREC, SERRS, and Cross County producer field (WCCPF).

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

Table 2. Data from the 2008 to 2009 Uniform Regional Rice Nursery for Roy J and other check cultivars.

	Yield[z]							50%	Kernel	Milling
Cultivar	AR	LA	MO	MS	TX	mean	Height	Heading	wt.[y]	HR:TOT[x]
	---------------------------- (bu/acre) ------------------------------						(in.)	(days)	(mg)	
Roy J	178	219	205	205	231	207	43	92	19.8	58:72
Taggart	188	229	195	212	246	214	44	89	22.0	57:72
Francis	163	216	176	214	206	190	39	87	17.9	59:71
Wells	176	224	176	194	219	196	41	88	20.7	59:72
Cybonnet	159	195	200	175	211	188	38	87	18.4	65:73

[z] 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.

[y] Kernel weight data is only collected in Arkansas.

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

Table 3. Preliminary Greenhouse Blast Race rating[z] of Roy J (based upon 2007 to 2009 ARPT data) with other comparative varieties.

	IB-1[y]		IB-49		IC-17		IE-1		IG-1		IH-1		IE-1K		IB-33	
Roy J	6	S	6	S	1	R	5	S	6	S	7	S	5	S	7	S
Taggart	5	S	5	S	6	S	6	S	7	S	6	S	4	MS	7	S
Banks	2	R	1	R	0	R	0	R	1	R	1	R	7	S	8	S
Cybonnet	1	R	0	R	0	R	0	R	0	R	0	R	6	S	6	S
Drew	1	R	0	R	0	R	0	R	0	R	0	R	6	S	6	S
Francis	6	S	7	S	8	S	6	S	7	S	1	R	6	S	7	S
Wells	7	S	7	S	7	S	7	S	2	R	0	R	6	S	7	S

[z] *Magnaportha grisea* races as defined using the international set of blast differentials. Plants in the 3- to 4-leaf growth stage were sprayed with spore suspension, held in moist chamber 12 to 18 hours then moved to greenhouse conditions. Composite leaf blast ratings on the 0 (none) to 9 (maximum) disease scale in multiple comparative inoculated greenhouse tests conducted at the University of Arkansas Rice Research and Extension Center, Stuttgart, Ark. Ratings indicate relative susceptibility under conditions favorable for seedling blast.

[y] Disease ratings vary between tests. For conversion of the 0 to 9 disease scale to symbols R (resistant) = 0 to 3, MR (moderately resistant) = 3 to 4, MS (moderately susceptible) = 5 to 6, S (susceptible) = 7, and VS (very susceptible) = 8 to 9. Varieties rated MS may be damaged and those rated S or VS may be severely damaged under favorable blast conditions.

BREEDING, GENETICS, AND PHYSIOLOGY

The Genetic and Economic Impact of Improved Blast Resistance in Arkansas Rice Varieties

L. Nalley and F.N. Lee

ABSTRACT

This study set out to quantify the value of genetic blast resistance [*Magnaportha grisea* (T.T. Hebert) M.E. Barr] in the most prevalent rice varieties sown in Arkansas. While each rice variety is given a broad rating of being "very susceptible, susceptible, moderately susceptible, resistant, and moderately resistant" to the blast disease, the underlying economic values of these ratings have not been estimated. Estimates from this study will allow producers, academics, and policy makers the ability to better quantify the economic value of genetic blast resistance in rice and the associated costs of mitigating blast in blast susceptible varieties. In an "average" growing season, blast "susceptible" varieties averaged a $2.38/acre cost while varieties rated as being "very susceptible" averaged a $12.23/acre cost to mitigate blast through fungicide use. During a highly conducive year such as 2009, these costs increased to $4.75 and $20.87/acre for the susceptible and very susceptible varieties, respectively. Given favorable conditions like 2009, the mitigation costs for the very susceptible 'Francis' variety were $10.43/acre higher than those of the more genetically resistant 'Wells' variety.

INTRODUCTION

Arkansas rice producers have multiple options when selecting rice varieties for their specific production practices and problems. Relative to the rice blast disease, safe options start with well-defined genetic blast-resistant varieties such as 'Cybonnet' or the newly released 'Templeton' which typically remain disease-free when growing in field conditions that are highly conducive for the blast disease. Conversely, very-susceptible varieties such as Francis and 'CL 151' are subject to excessive yield losses during weather conditions conducive for blast or by failure of the specific cultural practices required to induce blast field resistance. On occasion, growers tend to underestimate the value of genetic blast resistance, or select blast susceptible varieties without a full understanding of economic risks involved. In addition to the very obvious yield losses incurred, less obvious costs include the additional production costs incurred during the emergency salvage treatments made in attempts to avert or lessen the disaster. This research was undertaken to define these mediation costs.

PROCEDURES

To first quantify the economic value of genetic blast resistance, and the cost of mitigation, it was necessary to define what the rather broad terms of "susceptible, moderately susceptible, resistant, and moderately resistant" were in dollar terms. To do this several University of Arkansas plant pathologists were surveyed on the probability of applying a Quadris fungicide application to mitigate blast for the most prevalent rice varieties sown in Arkansas. While blast can be mitigated through proper irrigation practices, this study analyzes the estimated probability and the associated cost of an actual outbreak by variety. In this sense the probability of an outbreak was associated with the genetic level of blast tolerance that each variety possessed. The pathologists were asked to provide an estimated probability of a blast outbreak in an "average" growing year under "average" growing conditions. Next, they were asked to estimate what the maximum probability of having to apply fungicide for each variety was. This would represent a growing year which blast conditions were favorable. They were also asked to give the minimum probability that each variety would need to be treated with a fungicide, which represented a growing year with unfavorable blast conditions. Again, it should be stressed that while blast can be mitigated by proper flood control we are only analyzing the genetic blast susceptibility qualities and their associated probability of infection, *ceteris paribus*. Table 1 illustrates thirteen common rice varieties and their associated probabilities of requiring either one or two Quadris treatments to mitigate a blast outbreak.

Data were also collected over a five year period from 7 different Quadris suppliers and custom sprayers throughout the Arkansas Delta so that an average blast application cost across the state could be estimated. Given the cost of an application and the range of probabilities that a given variety would need an application of Quadris fungicide, an estimated cost could be calculated by variety under average, favorable, and unfavorable blast conditions. Given each variety had a minimum, maximum, and mean probabilities of an application it was assumed that the probability of favorable conditions was equal to that of unfavorable blast conditions, thus a normal distribution was used. A Monte Carlo simulation was implemented using 100,000 iterations to simulate a wide range of growing seasons (favorable, average, unfavorable blast conditions). The simulations also accounted for the variations in both Quadris and its application costs. From these iterations the cost of blast mitigation by variety could be calculated. Comparing cost differences amongst varieties highlights the economic value of the genetic resistance to blast.

RESULTS AND DISCUSSION

The simulation results show, intuitively, that blast resistant varieties like Cybonnet and the hybrids (723 and 729) have no application costs associated with them to mitigate blast (Table 2). The blast "susceptible" varieties (Wells, 'Cheniere', 'Jupiter', 'Bengal', 'CL 161', and 'CL 171') averaged a $2.38/acre cost to mitigate blast through the use of Quadris in an average growing season. Varieties classified as "very susceptible" to blast (Francis and 'CL 151') averaged a $12.23/acre cost to mitigate blast through the use of Quadris in an average growing season. This would indicate that on average varieties that are classified as genetically "very susceptible" incur a $9.85 increase in cost of production/acre compared to those varieties classified as genetically "susceptible" to blast. While producers take many factors into account (yield, presence of red rice, grain length, blast resistance, etc.) into account when selecting a rice variety, this research attempts to transform the existing qualitative blast ratings to a dollar amount per acre. Table 3 highlights the differences in the cost of blast mitigation by variety compared to the commonly sown Wells variety. This would indicate that, due to the genetic differences in blast resistance between Francis and Wells that on average Francis would incur a $6.14 higher/acre cost to mitigate blast.

While analyzing the probability of blast occurrence in an average year associated with a varieties genetic resistance it is also important to look at years with weather anomalies. Table 2 illustrates that when conditions conducive for blast occur, like in 2009, the per-acre costs increase to $4.75 and $20.87 for varieties that are blast "susceptible" and "very susceptible", respectively. This would indicate that when conditions are favorable for blast that varieties that are classified as genetically "very susceptible" incur a $16.12 increase in cost of production/acre compared to those varieties classified as genetically "susceptible" to blast. Table 3 shows the relative differences across varieties and indicates that because of the genetic differences between Francis and Wells that in the most favorable conditions for blast that Francis would incur a $10.43 higher per-acre cost to mitigate blast compared to Wells.

SIGNIFICANCE OF FINDINGS

The goal of this research was to take the broad categorization of qualitative blast resistance ratings and place an economic value on them with a mean and standard deviation. By doing so, this research sheds light on the economic value of blast research to producers in Arkansas. While there are proper management procedures a producer can undertake to reduce the probability of blast, genetics play an important role in reducing cost of production and yield losses associated with blast. Typically rice varieties are given a qualitative blast rating which often times is difficult to quantify into a dollar per acre amount. By placing an economic ($/acre) value on these qualitative genetic blast ratings this study provides producers, scientists, and policy makers information to better internalize what value of blast resistance is in financial terms.

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This research was conducted with the support of the Arkansas Rice Research and Promotion Board. The authors would like to thank Rick Cartwright for his input and assistance in this project.

Table 1. Genetic blast tolerance by variety and respective probabilities of Quadris applications.

Variety	Blast susceptibility rating	Probablity (%) of One Quadris application required for blast mitigation			Probability (%) of Two Quadris application required for blast mitigation		
		Min	Mean	Max	Min	Mean	Max
Wells	Susceptible	1	5	10	0	2	5
Francis	Very Susceptible	5	15	25	1	10	20
Cheniere	Susceptible	2	5	10	0	0	0
Cocodrie	Moderately Susceptible	0	0	0	0	0	0
Cybonnet	Resistant	0	0	0	0	0	0
Jupiter	Susceptible	1	10	25	1	5	10
Bengal	Susceptible	1	5	15	0	2	5
CL-131	Moderately Susceptible	0	0	0	0	0	0
CL-151	Very Susceptible	10	25	40	5	20	35
CL-161	Susceptible	0	0.5	1	0	0	0
CL-171	Susceptible	0	0.5	1	0	0	0
						0	0
XL 723	Resistant	0	0	0	0	0	0
XL 729	Resistant	0	0	0	0	0	0

Table 2. The average, minimum, and maximum costs per acre associated with blast mitigation attributed to genetic blast resistance differences amongst varieties.

Variety	Blast susceptibility rating	Simulated per acre cost of blast mitigation		
		Average	Minimum	Maximum
		($/acre)		
Wells	Susceptible	$2.67	$0.35	$5.22
Francis	Very Susceptible	$8.81	$2.09	$15.65
Cheniere	Susceptible	$1.97	$0.70	$3.48
Cocodrie	Moderately Susceptible	$0.00	$0.00	$0.00
Cybonnet	Resistant	$0.00	$0.00	$0.00
Jupiter	Susceptible	$6.03	$0.70	$12.17
Bengal	Susceptible	$3.25	$0.35	$6.96
CL-131	Moderately Susceptible	$0.00	$0.00	$0.00
CL-151	Very Susceptible	$15.65	$5.22	$26.08
CL-161	Susceptible	$0.17	$0.00	$0.35
CL-171	Susceptible	$0.17		$0.35
XL 723	Resistant	$0.00	$0.00	$0.00
XL 729	Resistant	$0.00	$0.00	$0.00

Table 3. The average, minimum, and maximum cost per acre differences in blast mitigation through the use of Quadris compared to the variety Wells.

Variety	Blast susceptibility rating	Cost difference		
		Average[z]	Minimum	Maximum
		($/acre)		
Francis	Very Susceptible	$6.14	$1.74	$10.43
Cheniere	Susceptible	-$0.70	$0.35	-$1.74
Cocodrie	Moderately Susceptible	-$2.67	-$0.35	-$5.22
Cybonnet	Resistant	-$2.67	-$0.35	-$5.22
Jupiter	Susceptible	$3.36	$0.35	$6.96
Bengal	Susceptible	$0.58	$0.00	$1.74
CL-131	Moderately Susceptible	-$2.67	-$0.35	-$5.22
CL-151	Very Susceptible	$12.98	$4.87	$20.87
CL-161	Susceptible	-$2.49	-$0.35	-$4.87
CL-171	Susceptible	-$2.49	-$0.35	-$4.87
XL 723	Resistant	-$2.67	-$0.35	-$5.22
XL 729	Resistant	-$2.67	-$0.35	-$5.22

[z] Calculated by subtracting the simulated mean cost of blast control using Quadris of each variety from the mean cost of the control variety (Wells). The reference variety is Wells, reference cost = 2.67, 0.35,and 5.22 $/acre for average cost, minimum cost, and maximum cost, respectively.

The 'Taggart' Rice Variety Has Enhanced Blast Field Resistance

F.N. Lee, K.A.K. Moldenhauer, and S.B. Belmar

ABSTRACT

Environmental conditions highly favorable for the rice blast [*Magnaportha grisea* (T.T. Hebert) M.E. Barr] disease during 2009 better defined rice blast field resistance for the newly released variety 'Taggart'. Average panicle blast severity ratings for the Taggart variety were 7.4 in tests at the University of Arkansas Pine Tree Research Station (PTRS) and 5.7 in tests at the University of Arkansas Rice Research and Extension Center (RREC) with an average severity rating of 6.6 over the two upland nurseries. These ratings were substantially lower than the corresponding severity ratings of 8.7 and 8.6 for the 'Wells' variety and ratings of 8.9 and 9.0 for the 'Francis' variety in the PTRS and RREC nursery plots, respectively. Average ratings over both nurseries were 8.6 for Wells and 8.9 for Francis.

Taggart is a new high yield variety with increased blast field resistance for Arkansas rice growers. Taggart apparently does not contain known partial resistance genes and could prove to be a valuable research tool to comprehend interactions between the blast fungus and the rice plant.

INTRODUCTION

Arkansas rice growers have long relied upon field resistance, often unintentionally, as their primary blast control strategy. Historically, new 'blast resistant' varieties with major resistance genes are typically overcome by the disease within 1 to 3 years due to pathogen adaptations which result in new races or an unexpected rapid increase of previously identified races. Once major gene resistance fails, Arkansas rice growers must rely upon inherent field resistance and cultural practices to control the rice blast disease.

In addition, many blast-susceptible varieties produce very high yields in the absence of rice blast disease and are preferred by knowledgeable rice growers who utilize cultural practices to achieve efficacious rice blast control. Since 2000, Arkansas growers have produced record per-acre rough rice yields while growing high yield blast susceptible varieties such as Wells and Francis. Blast control was achieved by growers manipulating cultural practices until the blast resistance expressed in Wells, Francis, and other susceptible varieties became comparable to that of major resistant gene varieties.

Unfortunately, most field resistant varieties are subject to substantial yield reduction when overwhelmed by rice blast during adverse environmental conditions including an extended drought or unexpected loss of flood water. Research data collected to date indicates the newly released Taggart variety (Moldenhauer et al., 2009) exhibits enhanced field resistance during environmental conditions that favor blast disease in the less resistant Wells and Francis. This research is part of our ongoing effort to better define and utilize field resistance as a blast control strategy.

PROCEDURES

Rice blast severity was evaluated on test entries growing in inoculated upland blast nurseries using the standard visual 0 to 9 scale where a 0 rating indicates complete disease immunity and the 9 rating indicates complete disease susceptibility usually ending with total yield loss and/or plant death. Ratings are often summarized as visual ratings of 0 to 3 = R (resistant), 3 to 4 = MR (moderately resistant), 5 to 6 = MS (moderately susceptible to susceptible), 7 = S (susceptible), and 8 to 9 = VS (very susceptible). Plants were bulk inoculated with multiple blast races including IB-1, IB-49, IC-17, IE-1, IH-1, and IG-1 growing on ryegrass seed-corn mixture. Panicle blast ratings were made at R7 to R8 growth stages when grain is filled but before grain begins to mature.

Four replications of selected breeding lines were included in the nursery tests located at the University of Arkansas Pine Tree Research Station (PTRS) near Colt, Ark., and the University of Arkansas Rice Research and Extension Center (RREC) near Stuttgart, Ark. Additional plots of Taggart, Wells, and Francis were included within the standard inoculated blast nursery tests and visually rated to generate additional field data.

RESULTS AND DISCUSSION

Panicle symptoms on plants growing in the near perfect environmental conditions for the rice blast disease during 2009 clearly defined the newly released rice variety Taggart as having increased rice blast field resistance (Table 1). Average panicle blast severity ratings for the Taggart variety were 7.4 in PTRS tests and 5.7 in RREC tests with an average rating of 6.6 for both locations. These ratings were substantially lower than the corresponding ratings of 8.7 and 8.6 for the Wells variety and ratings of 8.9 and 9.0 for the Francis variety in the PTRS and RREC nursery plots, respectively. Average ratings over both locations were 8.6 for Wells and 8.9 for Francis. The 2009 data agree with data from PTRS nurseries conducted during 2005 thru 2008 where Taggart panicle blast ratings averaged 4.0 compared to 6.1 and 7.5 for Wells and Francis, respectively (Lee et al., 2009).

In terms of applied rice production ratings, disease reactions are assigned based upon observed disease severity during conditions favoring severe disease development in historical and recent test plots and grower fields across Arkansas. Wells, which has a susceptible (S) blast reaction rating, is generally considered to represent the minimum acceptable level of blast field resistance for use in Arkansas rice production fields. In comparison, Francis has a very susceptible (VS) blast reaction rating but is often grown by Arkansas producers willing to assume the economic risk because Francis has a high yield potential. Rice pathologists with the University of Arkansas Division of Agriculture strongly recommend that rice cultivars with a VS blast reaction rating be planted only in wide open fields with excellent water management (deeper consistent flood) and no strong history of neck blast disease, and then only by growers experienced in the management of blast.

Due to the limited production history, the blast reaction for Taggart is currently placed as being S but the rating may change with additional grower use. Although Taggart is obviously more resistant than Wells, the exact ranking of Taggart relative to maximum achievable field resistance in rice varieties requires additional research. Regardless, Taggart should serve Arkansas growers well when standard blast cultural control recommendations are followed.

SIGNIFICANCE OF FINDINGS

Taggart provides Arkansas rice growers a new high yield variety with increased blast field resistance relative to Wells, Francis, and other blast susceptible varieties.

Taggart represents progress in the search for increased blast field resistance. Taggart apparently does not contain known partial resistance genes and could prove to be a valuable research tool in efforts to understand basic interactions between the blast fungus and the rice plant.

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F.N. Lee, R.D. Cartwright, K.A.K. Moldenhauer, and S.M. Belmar. 2009. Rice blast control strategies for new rice cultivars 'Taggart' and 'Templeton'. *In:* R.J. Norman, J.-F. Meullenet, and K.A.K. Moldenhauer (eds). B.R. Wells Rice Research Studies, 2008. University of Arkansas Agricultural Experiment Station research Series 571:80-86. Fayetteville, Ark.

Table 1. Summary of panicle blast severity rating data from varieties in inoculated upland blast field nurseries located on the University of Arkansas Pine Tree Research Station, Colt Ark., 2005 to 2008, and 2009; and on the University of Arkansas Rice Research and Extension Center, Stuttgart, Ark., 2009.

		Panicle blast rating[z]			
	Resistance	PTRS		RREC	PTRS/RREC
Variety	source	2005-2008	2009	2009	2009
Taggart	Field	4.0	7.4	5.7	6.6
Wells	Field	6.1	8.7	8.6	8.6
Francis	Field	7.5	8.9	9.0	8.9
Templeton	Pi-ta	2.0	3.3	3.1	3.2
Cybonnet	Pi-ta	2.7	4.8	2.7	3.7
Banks	Pi-ta	3.7	5.3	2.5	3.9

[z] Standard visual rating scale 0 to 9 where 0 = resistant (R) and 9 = very susceptible (VS). Panicle blast ratings were made at R7 to R8 growth stages when grain is filled but before grain begins to mature.

[y] Upland nursery plants were artificially inoculated in 4- to 6-leaf growth stage with multiple blast races including IB-1, IB-49, IC-17, IE-1, IH-1, and IG-1. Upland plots were flooded as necessary with plants being intermittently drought stressed during the growing season.

PEST MANAGEMENT: DISEASES

Effectiveness of New Foliar Fungicides to Control Sheath Blight of Rice

C.E. Parsons, J.C. Robinson, J.A. Yingling, and R.D. Cartwright

ABSTRACT

Public evaluation of new foliar fungicides to control sheath blight [*Rhizoctonia solani* (Kuhn)], the most important U.S. rice disease, remains a high priority for the Division of Agriculture and Arkansas rice growers and consultants. Field trials in 2008 and 2009, conducted in the Grand Prairie rice-growing region of the state, showed that a newly formulated mixture of azoxystrobin and propiconazole called Quilt Xcel™ was highly effective in controlling sheath blight and protecting rice yield and milling quality. This new formulation appears to be a better fit for growers of highly susceptible long-grain semidwarf rice cultivars in the state than the older product, Quilt™. Serenade™ and Ballad Plus™ biofungicides were not effective, and fluoxastrobin showed inconsistent results and probably needs further rate range studies in rice.

INTRODUCTION

Sheath blight is the most important disease in southern U.S. rice production (Cartwright et al., 2004) and is the primary reason that foliar fungicides are used in rice in the U.S. Since the initial registration of azoxystrobin fungicide for rice in the United States in 1997, total rice acreage treated in Arkansas with fungicides has risen from 10% to more than 80% (confidential industry estimates, personal communications). The use of fungicides in rice based on IPM decision-making systems appears to have decreased during that time, with the majority of rice fungicide applications now made preventively based on growth stage of the crop.

All modern rice cultivars and hybrids are considered somewhat susceptible under conditions favorable for sheath blight development, however long-grain, semidwarf rice cultivars are considered most susceptible in commercial fields. These cultivars are routinely treated about 7 to 14 days past panicle differentiation to minimize damage, although other timings may be used based on other conditions (Groth, 2005; Groth and Bond, 2006).

The increased use of foliar fungicides in U.S. rice and increasing interest in fungicides for soybeans, corn, and wheat has maintained continued development and testing of "new" or reformulated fungicides for southern field crops. In recent years, "biopesticides" for disease control have been increasing, likely due to increasing interest in "organic", "sustainable", or other "more natural" production systems, as well as less stringent and less expensive registration requirements compared to traditional chemical fungicides.

Most rice growers, consultants and other workers in the field believe that all crop protection products need unbiased field testing by public universities and extension agencies under conditions typical of modern rice production in the south in order to determine the unbiased value of registered products; to best utilize the products under different conditions; and to help encourage registration of those with the most potential.

The objective of these studies was to determine the field efficacy of selected new foliar fungicides for control of sheath blight and for protection of yield and milling quality of rice under typical high yield growing conditions in Arkansas.

PROCEDURES

Availability of seed determined cultivar use, with CL 161® planted in 2008 and CL 131® in 2009. Both were semidwarf long-grain rice cultivars rated very susceptible to sheath blight disease. Cultivars were planted in a designated test area of a typical rice production field each year in Lonoke County, part of the Grand Prairie rice-production region of the state, and plot residue was rolled after harvest to prevent movement of residual treated grain and foliage.

Plots were planted on 22 April in 2008, and 25 April in 2009. In both years, planted plots were 7 row (7-in. spacing) × 25 ft long with a seeding rate of 100 lb/acre, planted at 0.5-in. depth in a conventional Dewitt silt loam soil seedbed, using a Hege® plot drill. After emergence, plots were trimmed to approximately 20-ft length using a specialized alley maker that applied glyphosate herbicide to rice in the alleys for uniform kill. Irrigation, weed and insect control were performed by the experimental site manager following University of Arkansas Cooperative Extension Service guidelines. Plots received 180 lb/acre N (as urea) in 2008 as a 3-way split (110-35-35) and 200 lb/acre N (as urea) as a 3-way split (120-45-35) in 2009. These rates were considered excessive according to extension recommendations, but total rates were typical of the region for many growers, and were used to encourage uniform disease development.

All plots were inoculated with 200 ml floating calcium alginate beads containing hyphal pieces of *Rhizoctonia solani* AG1-1A isolate RS 407 at panicle initiation by hand sprinkling between the center plot rows on 20 June in 2008 and on 19 June in 2009. Preventative fungicide treatments were applied on 14 July in 2008 and 8 July in 2009, 7 to 10 days after panicle differentiation, allowing initial infection but before noticeable vertical sheath blight development. Treatments were arranged in a randomized complete block design with four replications and applied using a compressed air, self-propelled plot sprayer calibrated to deliver 10 gpa volume using flat fan spray tips.

Plots were visually evaluated 28 days after fungicide application in both years, and vertical progress of disease rated using a 0 to 9 rating scale where 0 = no symptoms and 9 = 90% or more of the plot canopy height having symptoms. Plots were harvested with a small plot combine at grain maturity on 15 Sept. in 2008 and 25 Sept. in 2009. Other diseases were minimal and no phytotoxicity was noted for any of the tested products. Harvested grain was weighed and yield converted to bu/acre at 12% grain moisture. Subsamples were processed by Riceland Foods (Stuttgart, Ark.) to obtain head and total milled rice values using GIPSA procedures.

RESULTS AND DISCUSSION

In both years, a new formulation of azoxystrobin + propiconazole, now registered as Quilt Xcel™, consistently controlled sheath blight and resulted in significantly higher yield than untreated plots (Tables 1 and 2). Plots treated with 17.5 or 21 fl oz/acre of the formulated product reduced sheath blight severity 20 to 48% (Tables 1 and 2) and had up to 58 bu/acre higher yield in the 2009 test (Table 2). Also in 2009, treated plots had 3% higher head rice compared to the untreated plots (Table 2). Efficacy of this new product to control sheath blight in our studies was comparable to the commercial standard treatment Stratego™ (Tables 1 and 2) and in other trials was equivalent to Quadris™ (data not shown). Because Quilt Xcel™ contains more azoxystrobin per fl oz than Quilt™ fungicide, it may offer a better fit for growers planting highly susceptible Clearfield™ semidwarf long-grain cultivars now widely grown in Arkansas.

Other products tested were not as effective or consistent for control of sheath blight when compared to the fungicide standard, azoxystrobin, and did not always result in higher yields or milling quality when compared to untreated plots (Tables 3 and 4). For example, the biofungicides Serenade™ (Tables 3 and 4) and Ballad Plus™ (data not shown) did not control sheath blight under our test conditions or protect yield and quality. When mixed with azoxystrobin or azoxystrobin + propiconazole, we did not observe any additional efficacy compared to using azoxystrobin alone (Tables 3 and 4).

Fluoxastrobin, a strobilurin fungicide registered for use on other crops as Evito™, was less effective in controlling sheath blight than Quilt Xcel™ or Stratego™ (Table 2), but did result in significant yield protection compared to untreated plots in 2009 (Table 2). Given these results, it seems likely that the most effective rate for use of fluoxatrobin in rice has not been determined and additional rate range testing is warranted.

SIGNIFICANCE OF FINDINGS

Given the variability of environmental conditions and rice management practices in Arkansas, it remains clear that with respect to foliar fungicides, there is no "one" answer for effective and economical use. Information developed by this type of objective field testing offers the best assurance that growers will understand when to use these products and that the products fulfill expectations for disease control and protection of rice yield and quality. With the advent of Quadris™ fungicide in 1997, the use of foliar fungicides to control sheath blight and protect rice yields in the southern U.S. has become a mainstay of applied disease management for rice growers, and their impact has probably been underestimated with regard to increased yields and production stability over the past decade.

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Table 1. Effect of Quilt Xcel™ and fluoxastrobin on sheath blight and yield of CL 161® rice, 2008.

Treatment	Form	Rate	SHB[z]	Yield	Head rice	Total milled
		(fl oz/acre)	(0 to 9)	(bu/acre)	--------- (%)	--------
Untreated			6.5	147	62.8	68.8
Fluoxastrobin	480SC	3.0	6.2	145	62.8	68.3
Fluoxastrobin	480SC	4.0	6.5	150	61.5	68.5
Fluoxastrobin	480SC	5.7	5.8	149	62.5	68.5
Quilt Xcel™	264SC	21.0	4.5	152	62.5	68.0
Stratego™	250EC	19.0	6.2	147	61.3	68.0
LSD (P = 0.05)			0.8	NS	NS	NS

[z] Sheath blight severity where 0 = no disease and 9 = symptoms on 90% or more of canopy height.

Table 2. Effect of Quilt Xcel™ and fluoxastrobin on sheath blight and yield of CL 131® rice, 2009.

Treatment	Form	Rate	SHB[z]	Yield	Head rice	Total milled
		(fl oz/acre)	(0 to 9)	(bu/acre)	--------- (%)	--------
Untreated			8.4	138	59.5	65.0
Fluoxastrobin	480 SC	3	8.6	173	61.5	67.0
Fluoxastrobin	480 SC	4	8.2	166	61.3	66.8
Fluoxastrobin	480 SC	5.7	8.1	171	61.2	66.4
Quilt Xcel™	264 SC	17.5	5.9	194	61.4	66.4
Quilt Xcel™	264 SC	21	3.6	196	63.0	68.0
Stratego™	250 SC	19	5.1	185	64.0	69.0
LSD (P = 0.05)			1.3	20	3.1	2.5

[z] Sheath blight severity where 0 = no disease and 9 = symptoms on 90% or more of canopy height.

Table 3. Effect of Serenade™ biofungicide on sheath blight and yield of CL 161® rice, 2008.

Treatment	Form	Rate	SHB[z]	Yield	Head rice	Total milled
		(fl oz/acre)	(0 to 9)	(bu/acre)	----------- (%)	----------
Untreated check			7.3	139	66.8	69.5
Serenade ASO™	1.34% w/v	32	7.2	136	66.8	69.5
Serenade ASO™	1.34% w/v	64	7.8	133	66.6	69.3
Serenade ASO™ + Quadris™	1.34% w/v + 250 SC	32 + 4	5.9	141	67.0	69.3
Serenade ASO™ + Quadris™	1.34% w/v + 250 SC	64 + 4	6.2	145	67.5	70.0
Serenade ASO™ + Quadris™	1.34% w/v + 250 SC	32	5.0	151	66.8	70.0
Quadris™	250 SC	8.5	4.6	153	66.3	69.3
Quadris™	250 SC	12	4.3	168	67.0	70.0
LSD (P = 0.05)			0.9	7.6	NS	NS

[z] Sheath blight severity where 0 = no disease and 9 = symptoms on 90% or more of canopy height.

Table 4. Effect of Serenade™ biofungicide on sheath blight and yield of CL 131® rice, 2009.

Treatment	Form.	Rate	SHB[z]	Yield	Head rice	Total milled	Lodging[y]
		(fl oz/acre)	(0 to 9)	(bu/acre)	--------------------(%)------------------		
Untreated			8.2	121	55.5	64.0	77.5
Serenade ASO™	1.34% w/v	16	8.5	122	56.5	65.5	96.3
Serenade ASO™	1.34% w/v	32	8.5	114	55.0	64.0	55.0
Serenade ASO™ + Quilt™	1.34% w/v + 200 SC	16 + 21	8.2	142	57.0	64.3	33.8
Serenade ASO™ + Quilt™	1.34% w/v + 200 SC	32 + 21	8.1	148	58.8	65.8	40.0
Serenade ASO™ + Quadris™	1.34% w/v + 250 SC	16 + 9.2	7.7	165	61.3	67.8	5.0
Serenade ASO™ + Quadris™	1.34% w/v + 250 SC	32 + 9.2	7.2	172	62.0	68.8	0.0
Quilt™	200 SC	21	7.5	153	60.5	67.3	36.3
Quadris™	250 SC	12	6.2	188	61.8	67.8	0.0
Quadris™	250 SC	9.2	7.4	152	59.0	66.3	37.5
LSD (P = 0.05)			0.8	16	4.2	3.2	39.5

[z] Sheath blight severity where 0 = no disease and 9 = symptoms on 90% or more of canopy height.

[y] Lodging noted as percent of plot fully lodged.

Assessment of Disease Reaction of Advanced Southern U.S. Rice Germplasm in the Field

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ABSTRACT

On-farm evaluation of advanced rice lines was conducted each year in Arkansas using replicated disease monitoring plots, inoculated Uniform Regional Rice Nursery (URRN) observation plots at two locations, and at least two Arkansas Rice Performance Trial (ARPT) sites. Multiple observations and ratings were used to construct a disease reaction table. This table is compiled each year for rice cultivars grown in the state to provide growers with disease information prior to seed purchase. Ratings have suggested over time that southern rice germplasm–with the exceptions of hybrid rices–range from moderately susceptible to very susceptible in reaction to the major diseases of the region. This suggests that continued emphasis be placed on a balance of high yield and manageable disease resistance. While yield potential is of primary importance, the cultivar must also survive to harvest, and some levels of susceptibility to disease are not manageable by growers under southern U.S. conditions. Promising lines with high yield potential and manageable disease resistance have been identified and may soon result in better cultivars.

INTRODUCTION

Foliar diseases of rice in the southern U.S. continue to represent one of the most important yield constraints for the crop, estimated to cost 8% to 12% of yield and quality each year. Disease resistance is an essential trait in modern rice cultivars and rice cannot be grown profitably without at least a manageable level. Unfortunately, breeding for resistance is complex and often the actual reaction to a particular disease may not be discovered until the cultivar is exposed to multiple field environments, often in grower fields. As a result, each state conducts extensive field testing of developing rice lines in order to provide the best information on risk performance to growers when cultivars are released, and to guide the breeding program and prevent the release of cultivars highly susceptible to one or more diseases. Plant pathologists with the University of Arkansas Division of Agriculture assess many cultivars and advanced lines each year under a multitude of field situations in the state, sometimes with surprising results.

PROCEDURES

Replicated yield plots of commercial cultivars were planted on 10 to 15 cooperating farms across the rice-production region of the state in each of the past several years, with sites in all of the major rice counties (Branson et al., 2009; Cartwright et al., 2001). These plots were managed by the cooperating grower using their respective production practices, and diseases noted and evaluated at heading each year. These on-farm plots were not inoculated.

In addition, non-replicated observation plots of entries in each year's Uniform Regional Rice Nursery (URRN) were planted on a cooperator farm in the Grand Prairie region (Lonoke Co.) of the state and on a research farm in northeast Arkansas with different soils and management practices (Yingling et al., 2008). The URRN site in Lonoke Co. was inoculated each year with the bacterial panicle blight pathogen, *Burkholderia glumae* (Kurita and Tabei) Urakami, using foliar sprays of fresh pathogen cell suspensions at late boot to early heading. The site in northeast Arkansas (Poinsett Co.) was inoculated with sclerotia and infested rough rice/rice hull mixture of the stem rot pathogen, *Sclerotium oryzae* Catt. to encourage uniform disease. Other diseases developed at these sites from natural inoculum.

At least two on-farm sites of the Arkansas Performance Trial entries were also evaluated each year, usually in Jackson and Clay counties.

Visual evaluations were made during heading to grain fill at all sites and diseases were identified and observations used to construct an updated disease reaction table for distribution to growers prior to seed purchase (Table 1) (Wilson et al., 2009).

RESULTS AND DISCUSSION

Diseases most frequently noted under field conditions in Arkansas during the past 2 to 3 years included sheath blight (*Rhizoctonia solani* Kuhn), straighthead, stem rot [*Magnaporthe salvinii* (Cattaneo) R. Krause and Webster I, neck blast [*Magnaportha grisea* (T.T. Hebert) M.E. Barr], black sheath rot (*Gaeumannomyces graminis* (Sacc.) Arx and D. Olivier), false smut [*Ustilaginoidea virens* (Cooke) Takah.], kernel smut [*Tilletia barclayana* (Bref.) Sacc. and Syd. in Sacc.], and bacterial panicle blight [*Burkholderia glumae* (Kurita and Tabei 1967) Urakami et al., 1994]. Other diseases observed included narrow brown leaf spot [*Cercospora janseana* (Racib.) O. Const.], brown spot [*Cochliobolus miyabeanus* (Ito and Kuribayashi) Drechs. ex Dastur], leaf smut (*Enty-*

loma oryzae Syd. and P. Syd.), aggregate sheath spot (*Ceratobasidium oryzae-sativae* Gunnell and Webster), and sheath spot (*Rhizoctonia oryzae* Ryker and Gooch).

RiceTec hybrids were the most resistant to diseases in general, followed by medium-grain cultivars (Table 1). Long-grain conventional cultivars had the most problems, but varied widely in reaction (Table 1). The new Clearfield® cultivar, 'CL 111', was very susceptible to sheath blight and stem rot, and susceptible to blast and straighthead (Table 1). 'CL 261', a new Clearfield® herbicide-tolerant medium-grain cultivar, appeared susceptible to bacterial panicle blight and straighthead, but appeared less susceptible to sheath blight, stem rot, and other diseases in 2009 at the single location observed (Table 1). 'CL 181 AR', a semidwarf Clearfield® long-grain, was found to be highly susceptible to bacterial panicle blight in test plots, while Clearfield® 'CL 142 AR' appeared susceptible to blast under highly favorable conditions (Table 1).

Over three years, 'Jupiter' was found to more susceptible to sheath blight than other medium-grains, and more susceptible to blast than originally believed (Table 1). Jupiter has remained resistant to bacterial panicle blight to date; however, 'Neptune' was inconsistent in resistance to bacterial panicle blight and has recently been rated susceptible (Table 1). A new long-grain cultivar, RU0801076 = 'Roy J' with high yield potential, was moderately susceptible to susceptible in reaction to most diseases, including false smut under 2009 conditions (Table 1).

The new cultivar, 'Templeton', remained highly resistant to blast across Arkansas but was more susceptible to straighthead than once anticipated (Table 1). 'Taggart', a new cultivar, was moderately susceptible to susceptible in reaction to many diseases but showed no highly susceptible reactions (Table 1). 'Catahoula' was highly susceptible to sheath blight in Arkansas but remained resistant to blast over the last three years (Table 1). 'Jazzman' and 'JES', aromatic cultivars, tended to be intermediate in reaction to most diseases in our state but JES was very susceptible to stem rot and lodged as a result at several sites (Table 1).

The conditions for heading disease development were nearly ideal during 2009 in Arkansas. The crop was planted late, due to spring planting delays from excessive rainfall, and cloudy rainy weather persisted through the summer and into October. It was a record rainfall year for many areas of the state, with almost four times normal rainfall in July, a critical disease development month for the Arkansas rice crop. As a result, Arkansas experienced major neck blast epidemics in grower fields in Arkansas, Phillips, Lee, St. Francis, Monroe, Prairie, Lonoke, White, Woodruff, and Jackson counties; and sporadic blast problems in Independence, Lawrence, Craighead, Poinsett, Cross, and Crittenden counties. We observed yield losses up to up to 80% in affected fields of 'Francis' and Clearfield® CL 151; and up to 50% in Jupiter and a few 'Wells' fields. Of the 52 severely damaged fields we inspected, 20 were CL 151 (rated very susceptible to blast); 17 were Francis (very susceptible); 11 Jupiter (susceptible), and 4 Wells (susceptible). We also observed some damage in fields of 'Bengal' and 'Cheniere' in the region. While we received reports of RiceTec hybrids with blast, we were not able to confirm blast in any hybrid field inspected. Symptoms of brown spot and narrow brown leaf spot disease on panicles of hybrid rices were confused with blast symptoms by growers and consultants in a few cases. In every field with severe damage, there were problems with flood depth, at least with regard to managing blast disease. To minimize blast, fields should be flooded to a 4-inch minimum depth (shallowest part of the paddy) and this depth held consistently throughout the growing season. In damaged fields, growers often turned off the pumps to save fuel or electricity costs, since it was raining frequently. The result was erratic or shallow flood depth, and wet plant tissue from rainfall; a near worst-case scenario for blast disease.

In addition, the Arkansas rice crop in 2009 suffered from widespread false smut disease for the second year in a row, with many complaints from growers about this difficult-to-control problem. Observations again suggested that all cultivars were susceptible to false smut, but varied in severity, with hybrids and medium-grain cultivars being the least susceptible and long-grain cultivars the most susceptible under similar conditions. Fields with severe false smut typically received excessive nitrogen fertilizer in the preflood application.

Reactions of URRN (Uniform Regional Rice Nursery) entries over the past few years in Arkansas suggest that most entries under development are moderately susceptible to very susceptible to major diseases (Table 2). For example, 76% of the URRN entries evaluated during 2009 at the neck blast disease nursery at the Pine Tree Research Station were found to be susceptible to very susceptible to one or more races of the blast pathogen (Table 2). While yield potential is a primary breeding trait in the south, manageable disease resistance is critical for risk management on many producer farms. Current hybrid rices grown in the southern U.S. represent a more ideal balance of high yield potential and low risk potential (from disease threats) and the search for this balance in conventional cultivars should be emphasized.

With that in mind, Table 3 lists the URRN entries with the highest yields in 2009 across the five participating states, along with their yield performance in Arkansas, and reaction to major diseases in our state using a numerical 0 to 9 rating scale (0 = no disease and 9 = severe disease). Clearly, we need to focus on breeding a more ideal balance of high yield and low risk in conventional and Clearfield® southern rice germplasm.

SIGNIFICANCE OF FINDINGS

The development of improved rice cultivars remains of foremost importance to U.S. rice producers, but “improved” does not just mean “high yield”, it also means excellent stability and manageable resistance to production risks, including diseases. The incorporation of high yield and acceptable risk management are not mutually exclusive goals, as demonstrated by the current hybrid rices, as well as cultivars like Wells and Cheniere. This research demonstrates the need for increased research on the development of high yielding, low risk rice cultivars in the south.

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Table 1. Disease reactions for commercial rice cultivars under Arkansas field conditions, 2009.

Cultivar	Sheath blight	Blast	Straight-head	Bacterial panicle blight	Narrow brown leaf spot	Stem rot	Kernel smut	False smut	Lodging	Black sheath rot
Medium-grains										
Bengal	MS[z]	S	VS	VS	S	VS	MS	MS	MR	MR
CL 261	MS	S-VS	S	S	S	S	MS	S	MR	MS
Jupiter	S	S	S	MR	MS	VS	MS	MS	MS	MR
Neptune	MS	MS	VS	S	MS	VS	MS	MS	MR	MR
Hybrids										
Arize1003	MR	R	VS	MR	MR	MR	MS	MS	S	MR
RT CLXL729	MS	R	MS	MR	MS	MS	MS	S	S	MS
RT CLXL745	MS	R	R	MR	MS	MS	MS	S	S	MS
RT XL723	MS	R	S	MR	MS	MS	MS	S	MS	MS
Clearfield long-grain cultivars										
CL111	VS	S	S	S	VS	VS	S	S	MS	S
CL131	VS	MS	VS	VS	VS	VS	S	S	MR	S
CL142-AR	MS	S	MS	S	S	S	S	S	MS	S
CL151	S	VS	VS	VS	S	VS	S	S	S	VS
CL161	VS	S	MS	S	S	VS	S	S	MS	S
CL171-AR	VS	S	MS	S	S	VS	S	S	MS	S
CL181-AR	VS	S	MS	VS	S	VS	S	S	MR	S
Conventional semidwarf long-grain cultivars										
Bowman	MS	VS	R	S	MR	VS	MS	S	MR	MS
Catahoula	VS	R	MS	S	MR	S	S	S	MR	MS
Cheniere	S	S	MR	S	S	S	S	S	MR	S
Cocodrie	S	S	VS	S	S	VS	S	S	MR	S
Cybonnet	VS	R	R	S	S	VS	S	S	MS	S
Conventional standard height long-grain cultivars										
Francis	MS	VS	MR	VS	S	S	VS	S	MS	MS
Roy J	MS	S	S	S	MR	S	S	S	MR	MS
Taggart	MS	S	R	MS	MS	S	S	S	MS	MS
Templeton	MS	R	S	S	S	MS	S	S	MS	MS
Wells	S	S	MS	S	S	VS	S	S	MS	MS

continued

Table 1. Continued.

Cultivar	Sheath blight	Blast	Straight-head	Bacterial panicle blight	Narrow brown leaf spot	Stem rot	Kernel smut	False smut	Lodging	Black sheath rot
Aromatic long-grain cultivars										
JazzMan	MS	S	S	S	S	S	MS	S	MS	MS
JES	MS	R	MR	MS	R	VS	MS	MS	S	MR

[z] R = resistant; MR = moderately resistant; MS = moderately susceptible; S = susceptible; VS = very susceptible.

Table 2. Summary disease reactions of URRN rice lines in Arkansas, 2007-2009.

Disease reaction[z]	Neck blast	Sheath blight	Bacterial panicle blight	Stem rot	Black sheath rot
R	6	0	0	0	1
MR	12	0	13	8	28
MS	7	26	40	27	43
S	22	43	38	44	17
VS	54	32	10	22	11

[z] R = resistant; MR = moderately resistant; MS = moderately susceptible; S = susceptible; VS = very susceptible.

Table 3. Yield and disease reaction for promising rice lines in the Uniform Regional Rice Nursery, 2009.

			2009 URRN		Disease reaction in Arkansas 2009^z						
Variety	Grain type	State	5 State average yield	Arkansas average yield	Neck blast	Sheath blight	Bacterial panicle blight	Stem rot	Black sheath rot	Kernel smut	False smut
			-------- (bu/acre) -------								
RU0902162	M	LA	215	212		5.0	7.0	8.0	4.0	4.0	6.0
RU0801142	L	AR	213	182	8.7	6.8	6.0	7.0	6.0	7.0	7.0
RU0801081	L	AR	212	226	9.0	7.8	4.0	6.0	4.0	8.0	7.0
RU0801185	L	AR	210	202	8.7	6.8	7.0	5.0	3.0	7.0	7.0
RU0802008	L	LA	210	173	7.3	8.0	6.0	5.0	4.0	7.0	7.0
RU0801161	L	AR	208	212	5.0	7.0	6.0	7.0	6.0	7.0	7.0
RU0801176	L	AR	206	184	9.0	7.0	5.0	5.0	3.0	7.0	8.0
RU0801182	L	AR	203	188	8.3	7.0	7.0	5.0	3.0	6.0	7.0
RU0902177	L	LA	202	195	8.7	7.5	3.0	3.0	4.0	7.0	7.0
RU0902152	L	LA	202	189	8.7	6.0	6.0	8.0	7.0	7.0	7.0
RU0802022	L	LA	202	174	8.7	7.5	6.0	5.0	3.0	7.0	7.0
RU0802091	L	LA	202	173	8.7	7.3	3.0	5.0	4.0	7.0	7.0
RU0702068	M	LA	202	179	5.0	6.0	7.0	7.0	6.0	4.0	6.0
RU0801076	L	AR	200	191	8.7	5.5	4.0	5.0	3.0	7.5	8.0
RU0702085	L	LA	200	194	8.3	6.5	2.0	7.0	6.0	7.0	7.0
RU0902011	L	LA	200	158	7.5	7.3	3.0	7.0	6.0	7.0	7.0
Other URRN entries of interest for other traits											
RU0802140	L	LA	184	159	7.7	6.3	3.0	7.0	6.0	6.0	6.0
RU0803092	L	TX	189	166	6.7	7.0	2.0	8.0	5.0	6.0	6.0
RU0703190	L	TX	153	184	8.5	6.0	8.0	5.0	5.0	6.0	6.0
RU0703144	L	TX	156	186	7.3	7.3	7.0	8.0	5.0	6.0	6.0
RU0804083	L	MS	161	209	8.3	6.8	7.0	7.0	7.0	7.0	7.0
RU0802149	L	LA	124	161	3.7	7.3	7.0	7.0	5.0	6.0	6.0

[z] 0 to 9 disease rating scale where 0 = no disease and 9 = very severe disease.

Developing Cold-Tolerant Cultivars with Seedling Disease Resistance to *Pythium* Species: Evidence for and Nature of Resistance in RU0701124

C.S. Rothrock, R.L. Sealy, J.W. Gibbons, and F.N. Lee

ABSTRACT

Pythium species are the most common seedling disease pathogens isolated from rice in producers' fields in Arkansas. These studies examined the value of *Pythium* resistance in breeding lines with cold tolerance in early-season planting environments. These lines show promise for reliable stand establishment in Arkansas. The breeding line RU0701124 had more plants/acre and greater relative root weight and above-ground dry matter than 'Kaybonnet' and was similar to the moderately resistant PI evaluated in these studies. In addition, the research demonstrated that the breeding line RU0701124 had lower frequency of isolation of the *Pythium* spp. and less root discoloration than Kaybonnet in the field. The research points to the value of screening rice for resistance to *Pythium* spp. in developing breeding lines as part of the cold tolerance breeding program.

INTRODUCTION

Developing cultivars with greater cold tolerance in rice would allow the crop to be planted earlier to take advantage of spring rainfall. These cultivars would need to be tolerant to cold soil temperatures at planting, as well as more variable environmental conditions. Under these marginal environments, stand problems associated with *Pythium* seed and root rot caused by several *Pythium* spp. is greatly increased. Seed treatment fungicides are effective in increasing stands in some situations. However, identifying resistance to this group of seedling disease pathogens would be important for an early production system to be successful. *P. arrhenomanes* and *P. irregulare* are often the most important seedling pathogens on rice and damage is increased under cold soil temperatures (Cother and Gilbert, 1993; Eberle et al., 2008; Rush, 1992). Other less virulent *Pythium* species isolated from rice include *P. catenulatum*, *P. torulosum*, and *P. diclinum* (Eberle et al., 2008).

Research funded by the Arkansas Rice Research and Promotion Board has identified promising cold-tolerant *Pythium*-resistant rice genotypes which can reliably establish stands in marginal planting environments in Arkansas rice fields (Rothrock et al., 2003, 2004, 2005, 2006). Of the 346 genotypes of rice evaluated from James Gibbons' program for the ability to germinate and grow at cold soil temperatures, only 8% of the genotypes had stand counts in the *Pythium*-infested treatment comparable to or better than those of the resistant control, indicating at least moderate resistance (Rothrock et al., 2006). Selected genotypes have been evaluated in the field to confirm their cold tolerance and *Pythium* resistance and validate the screening procedure. These studies have identified specific genotypes with cold tolerance and *Pythium* resistance. This paper provides additional evidence for the nature of this resistance using the breeding line RU0701124 (STG03P-07-048) from the cold tolerance breeding effort at the University of Arkansas that has repeatedly shown resistance to *Pythium* spp.

PROCEDURES

A series of experiments were conducted in the field and controlled environmental conditions to examine resistance using plant introductions, widely grown cultivars, and cold-tolerant breeding lines.

Three planting date studies at three locations in Arkansas were conducted in 2009 similar to previous seasons. Planting dates in 2009 ranged from 6 March to 21 April. The test locations were Pine Tree Research Station at Colt, Northeast Research and Extension Center at Keiser, and Rice Research and Extension Center at Stuttgart representing the White River, Delta, and Grand Prairie ecosystems, respectively. In 2009 each genotype received the seed treatments: 1) not treated or 2) Allegiance, 1.5 oz/cwt (metalaxyl). Each test was a split-plot design with genotype as the main plot and fungicide treatment as the subplot. Analyses included stand and relative stand, stand of the fungicide-treated seed divided by stand of the nontreated seed treatment. For the second planting date (23 March) at Stuttgart in 2009, 10 seedlings were dug from each plot and plant weight, root discoloration, and isolation of *Pythium* spp. from the below-ground portions of the plant were recorded. Rice seedlings were washed for 20 minutes in running tap water and roots and coleoptiles were assessed for disease. Roots from seedlings were disinfested in 0.5% NaOCl, blotted dry, and plated on amended water agar (WArad). After 3 to 5 days, unique colony growth was transferred to potato dextrose agar (PDArad) and identified to genus. The root discoloration scale was a 1 to 5 scale with 1 = 0%, 2 = 1 to 10%, 3 = 11 to 25%, 4 = 26 to 50%, and 5 = 51 to 100% discoloration.

For controlled environmental studies, the pathogen used in this study was an isolate of *Pythium arrhenomanes* from rice seedling roots from an Arkansas rice field.

Previous work in this laboratory has demonstrated this isolate to be virulent to rice seeds and seedlings at various soil temperatures. Inoculum of *P. arrhenomanes* was grown on sand-corn meal media for 10 days prior to adding to soilless potting media for the infested treatments. Nylon screening was cut and placed in the bottom of each pot (60-cm diameter) to retain the vermiculite potting substrate. Pots for non-infested treatments were filled two-thirds with sterile vermiculite. For infested treatments, pots were filled one-third with sterile vermiculite and then another third with vermiculite that was infested at the rate of 34 g of inoculum per pot. Inoculum was thoroughly mixed into the vermiculite prior to placement into each pot. The three genotypes of rice were PI560281 (cold tolerant and moderately resistant to *Pythium*), Kaybonnet (cold tolerant, but susceptible to *Pythium*), and RU0701124 (cold-tolerant and moderately resistant to *Pythium*). Ten seeds were planted in each pot. Infested and non-infested treatments had four replications each. After planting, pots were placed in a growth chamber kept at a constant temperature of 68 °F (20 °C) with a 12-hr photoperiod. Stand counts were collected five weeks after planting. Data were analyzed as relative stand, which is percentage of the stand for a plot compared to the mean of the noninfested controls for that genotype. Relative fresh weight and above-ground dry matter also were recorded for seedlings by dividing seedling weight by the mean of the non-infested controls for each genotype.

RESULTS AND DISCUSSION

Screening in controlled environments identified a number of genotypes with potential resistance to *Pythium* spp. Field studies demonstrated RU0701124 was one of the best performing breeding lines for stand establishment under marginal environments compared to Kaybonnet and other cultivars and genotypes and was similar to the moderately resistant PI, PI 597085 (Rothrock et al., 2006). Additional studies have confirmed the *Pythium* resistance in RU0701124 resulted in improved stand establishment compared to other genotypes.

The importance of *Pythium* resistance in rice genotypes after the seedling stage, over a wide range of temperatures, was examined using RU0701124 in field and controlled environmental studies. In the controlled environmental study, three genotypes were examined; PI560281, RU0701124, and Kaybonnet. This study was conducted at 68 °F to decrease disease pressure from *Pythium*, allowing greater seedling survival. The stand data confirms *Pythium* resistance for stand establishment in RU0701124 (Table 1). In addition over a period of 8 weeks, surviving seedlings of RU0701124 had a relative root weight and above-ground dry matter equivalent to the moderately resistant PI and much greater than those of Kaybonnet (Table 1).

In 2009, seedlings also were examined from one of the field studies using the same genotypes and the cultivar ‘Wells.’ Data for isolation of *Pythium* spp. showed an interaction between genotype and metalaxyl treatment. In the absence of the metalaxyl seed treatment to control seedling diseases caused by *Pythium* spp., RU0701124 had fewer seedlings from which *Pythium* was isolated compared to the cultivars Kaybonnet and Wells and was not significantly different from PI560281. For metalaxyl-treated seed, isolation from Kaybonnet seedlings was reduced compared to seed with no seed treatment, but no further reduction was found for the other genotypes. Root discoloration was also lower numerically for PI560281 and RU0701124 than the two cultivars and these ratings were significantly lower for these two genotypes than ratings for Kaybonnet.

Screening of genotypes for levels of *Pythium* resistance is continuing for materials out of the cold-tolerance breeding program. Research is quantifying the importance of *Pythium* resistance in rice breeding lines beyond the seedling stage over a range of environments and durations. This research suggests that the resistance being developed as part of the cold-tolerance breeding program should have benefits for rice production. If this resistance is demonstrated past seedling emergence, it would suggest this trait may be more valuable than fungicide seed treatments to producers as a result of expressing resistance over an extended period rather than only for the period of activity of seed treatments.

SIGNIFICANCE OF FINDINGS

These studies have identified specific genotypes with cold tolerance and *Pythium* resistance for more reliable stand establishment in rice in Arkansas under marginal planting environments. The breeding line RU0701124 had greater stands and greater relative root weight and above-ground dry matter than Kaybonnet and was similar to the resistant PI evaluated. In addition, for a field study in 2009, RU0701124 had fewer seedlings from which *Pythium* was isolated compared to the cultivars Kaybonnet and Wells and was not significantly different from the moderately resistant genotype PI560281. Root discoloration was also lower for PI560281 and RU0701124 than for Kaybonnet. The research points to the value of screening rice for resistance to *Pythium* species in developing breeding lines in the cold tolerance breeding program.

ACKNOWLEDGMENTS

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Table 1. Response of selected genotypes to *Pythium arrhenomanes*[z].

Genotype	Relative stand	Relative fresh root weight	Relative fresh top weight
		------------------- (g) -------------------	
PI560281	0.97 a[y]	0.32 a	0.42 a
RU0701124	1.08 a	0.31 a	0.34 ab
Kaybonnet	0.54 b	0.11 b	0.17 b
P-value	0.0271	0.0271	0.0548

[z] Relative measurements are determined by the measurement of the variable in the container infested with *Pythium arrhenomanes* divided by the measurement for the mean of non-infested containers.

[y] Means followed by the same letter in a column are not significantly different, LSD (*p* = 0.05).

Table 2. Response of selected genotypes to *Pythium* seedling disease for Stuttgart (2nd planting date) 2009.

	Pythium isolation[z]		Root
Genotype	None	Metalaxyl	discoloration[y]
PI560281	76.7 bc[x]	67.5 cd	2.6 b
RU0701124	62.5 cd	62.5 cd	2.3 b
Kaybonnet	93.0 ab	46.7 d	3.6 a
Wells	100.0 a	97.5 ab	3.2 ab

[z] *Pythium* isolation interaction at *P* = 0.10.

[y] Root discoloration, scale 1 to 5 (*P* = 0.05).

[x] Means followed by the same letter for a variable are not significantly different, LSD (*p* = 0.05).

PEST MANAGEMENT: INSECTS

Control of Rice Stink Bugs with Foliar Application of Dinotefuran and Clothianidin

J.L. Bernhardt

ABSTRACT

The rice stink bug [*Oebalus pugnax* (F.)] is one of the important pests commonly found in Arkansas rice fields. When outbreaks in fields reach critical levels, an insecticide application is an option. Pyrethroid and organophosphate insecticides usually give excellent contact mortality, but both groups lack any significant residual activity. Two insecticides, dinotefuran and clothianidin, were tested in a field study for control of rice stink bugs through contact and residual activity. Both insecticides had excellent contact mortality and significantly better residual activity than historically provided from the commonly used pyrethroid and organophosphate insecticides. The residual activity decreased somewhat at the end of 7 days for clothianidin and at the end of 10 days for dinotefuran. However, the residual activity could have been affected by rainfall that occurred on the fourth, sixth, and ninth day of the test. Registration of both insecticides is being encouraged by researchers and pursued by the chemical companies.

INTRODUCTION

Rice lines have different levels of susceptibility to organisms that discolor kernels (Bernhardt, 1992). In the field, kernel discolorations are caused by fungi alone, such as kernel smut [*Tilletia barclayana* (Bref.) Sacc. and Syd. in Sacc.] or by fungi introduced by the rice stink bug, *Oebalus pugnax* (F.), and by physiological responses to adverse environmental conditions during grain fill. Agents that discolor rice kernels are commonly found in all Arkansas rice fields. The majority of discolored kernels are a result of feeding by rice stink bug adults and nymphs. Stink bugs can feed on rice kernels at all stages of development except at hard dough and maturity. Feeding during the early stages of kernel development prevents grain fill and results in light-weight, immature kernels. Feeding during the later stages of development often results in only a portion of the contents being removed. But after the hull of any stage kernel is pierced by rice stink bugs, fungi gain entry and the infection results in a discoloration of the kernel. The amount of damage by rice stink bugs often influences the acceptability and value of rough rice. Such was the case in 2001 and 2002 when rice fields were highly infested with rice stink bugs. Grain inspections by rice buyers during those years found unusually high levels of discolored kernels that decreased the value of grain by as much as $0.25/bu.

The entomology research program places emphasis on the development of control strategies that integrate control methods such as more resistant rice lines, insecticides, and rice stink bug parasites. A portion of the program evaluates insecticides for contact and residual control of rice stink bugs. The overall objective is to provide information to the chemical industry on the efficacy of candidate insecticides. A product that gives excellent contact control plus an extended residual control is sorely needed in rice. This report is a summary of field tests investigating the use of the insecticides dinotefuran (Tenchu®) and clothianidin (Belay®) for control of rice stink bug.

PROCEDURES

Rice was drill-seeded at 90 lb/acre in plots 9 rows (7-in. spacing) × 35 ft. on 22 April and emerged on 5 May 2008. Permanent flood was established on 4 June and plots were 50% headed by 29 July.The experimental design was a randomized complete block with three replications. Each large plot was divided into seven subplots and the subplots were randomly assigned one of seven time periods after treatments were applied. Two days before plots were treated, rice stink bug adults were collected from rice fields and adjacent weedy areas. Adults were placed in 5 gallon plastic buckets containing panicles cut from heading rice and weeds. Nylon tull sleeve cages that had a 4-in. diameter and were 14 in. long were used to confine adults on rice panicles. Cage tops were closed with a twist tie and approximately 60 minutes before insecticides were applied to field plots, three adults were placed in a cage and herded to the top end. A string was tied just below the adults to keep the bugs confined to the top end. About 30 minutes before applications, cages with bugs were placed in the plots. Three panicles were chosen, the flag leaf on each plant was removed to reduce refuges from spray contact, the cage and bugs were slipped over the panicles, the cage was closed around the plant stems, tied with a twist tie, and the string removed so that bugs could move freely within the cages. Insecticides were applied on 6 August by a backpack sprayer at 18.8 gpa. Treatments were 1) untreated (check); 2) lambda cyhalothrin (KarateZ®) at 0.03 lb ai/acre (standard); 3 and 4) dinotefuran (Tenchu®) at 0.066 and 0.132 lb ai/acre, respectively; and 5, 6, and 7) clothianidin (Belay®) at 0.093, 0.145, and 0.180 lb ai/acre, respectively. The same procedures of bug confinement and cage placement was used when subsequent cages were placed in the subplots except the flag leaves were not removed. To test for residual activity, cages with bugs were placed over panicles at 1, 2, 3, 5, 7, and 10 days after treatments were applied. Cages remained in the field for three days. After the 3-day exposure time, plants were cut below the cage, taken to the laboratory, and number of dead bugs counted.

Subplots were harvested on 25 September. Dried and uncleaned rough rice samples (0.25 lb) were taken from each subplot and then hulled. Brown rice was passed three times through an electronic sorting machine that separated discolored kernels from other kernels. The discolored kernels were examined with magnification to determine the cause of the discoloration. The amount of kernels discolored by rice stink bugs was weighed and expressed as a percentage of the total weight of brown rice. All data were analyzed with PROC ANOVA (**S**tatistical **A**nalysis **S**ystem) and means separated by LSD. The arcsin transformation was used for percent mortality data prior to data analysis.

RESULTS AND DISCUSSION

All three insecticides had excellent contact mortalities of adults in cages that were present before applications were made (Table 1). Mortalities of bugs placed over panicles one day after applications were also excellent. This was truly a surprise that bugs had 89% mortality the next day after foliar treatment with lambda cyhalothrin (KarateZ). Usually with KarateZ, observed mortalities one day after treatment have been between 0 and 20% (Bernhardt, 2000 and unpublished data). Even more surprising was mortalities of caged rice stink bugs also occurred on days 2 through 7 after treatment with KarateZ. The results in this test with KarateZ have never been observed in any other similar test.

Cages placed over treated foliage on days 2 through 10 showed the residual activity of dinotefuran, clothianidin, and the unexpected activity of KarateZ (Table 1). During this test, rain fell on the plots three times (Table 2) and may have influenced the outcome. What is noticeable is that residual activity did not follow a dosage rate response and was uneven among the treatments with cages placed on the third, fifth, and seventh days after applications. It is generally known that rainfall after application usually influences the performance of insecticides. Perhaps performance was enhanced as in the unexpected activity of KarateZ. As stated earlier, previous tests with KarateZ had minimal activity after 24 hours, but in those tests there was no rainfall and only sunny hot days. Previous tests with dinotefuran and clothianidin in Texas demonstrated high residual activity, so these results were expected and the rainfall may have affected expected dosage rate responses. The rainfall could have affected the length of residual activity of dinotefuran and clothianidin and prevented more activity 10 days after treatment. In this test, the rates of dinotefuran tested had a slightly longer time of residual activity than that of clothianidin.

Application of insecticides to control rice stink bugs are to prevent or reduce the amount of damage to rice kernels (pecky rice). These insecticides were applied ten days after 50% heading and this single application reduced the amount of pecky rice by about 50% of that found in the untreated plots (Table 3).

SIGNIFICANCE OF FINDINGS

The goal of part of the rice insect project is to provide growers with management options for control of rice insect pests. The insecticides dinotefuran and clothiandin appear to be excellent candidates. Both gave excellent contact control of rice stink bugs and 7 to 10 days of residual control. Any residual activity is what is lacking with currently registered pyrethroid and organophosphate insecticides. The two insecticides, if registered, would be welcomed by rice growers for it is obvious that pecky rice can be reduced by only one or two applications during heading with an insecticide with residual activity.

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Table 1. The average percent mortality of rice stink bug adults caged over rice panicles sprayed with three insecticides, RREC, 2008.

		Days after treatment when cages placed over panicles						
Treatment	Rate	0[z]	1	2	3	5	7	10
		(% mortality)						
Untreated		0 b	0 b	0 b	0	0	0	0 b
λ-cyhalothrin	0.03	100 a	89 a	75 a	50	75	25	0 b
Clothianidin	0.093	100 a	100 a	0 b	100	100	50	0 b
Clothianidin	0.145	100 a	100 a	75 a	75	50	25	0 b
Clothianidin	0.180	100 a	100 a	75 a	75	100	50	0 b
Dinotefuran	0.066	100 a	100 a	50 a	50	50	25	25 a
Dinotefuran	0.132	100 a	100 a	50 a	100	100	100	25 a
				NS	NS	NS		

[z] Cages placed before insecticide application, thus giving a rating for contact mortality.

Table 2. Dates and times of cage placement and removal to assess the contact mortality and residual activity of three insecticides for rice stink bug control, RREC, 2008.

Cages placed	Cages removed	Hours after treatment	Days after treatment
8/6	8/9	0.5 hr. before	0
8/7	8/10	24	1
8/8	8/11 (rain 8/10)[z]	48	2
8/9	8/12	72	3
8/11	8/14 (rain 8/12)	120	5
8/13	8/16 (rain 8/15)	168	7
8/16	8/19	240	10

[z] Rainfall amounts were 0.81, 0.7, and 1.45 inches on 8/10, 8/12, and 8/15, respectively.

Table 3. The average percentage of brown rice kernels (by weight) that were damaged by rice stink bugs in plots sprayed with three insecticides, RREC, 2008.

Treatment	Rate	Percent damage from rice stink bug
	(lb ai/acre)	(% damage by weight)
Untreated	-	1.10 a
Lambda-cyhalothrin	0.03	0.38 b
Clothianidin	0.093	0.52 b
Clothianidin	0.145	0.52 b
Clothianidin	0.180	0.50 b
Dinotefuran	0.066	0.43 b
Dinotefuran	0.132	0.51 b

Genetic Characterization of the Panicle Rice Mite, *Steneotarsonemus spinki* (Acari: Tarsonemidae)

A.P.G. Dowling, R.J. Sayler, and R.D. Cartwright

ABSTRACT

The panicle rice mite, *Steneotarsonemus spinki* Smiley, has been a serious pest of rice (*Oryza sativa*) across tropical Asia and was recently introduced to the Americas in the late 1990s. The mite was recently found in the United States, primarily in greenhouse and research facilities in Texas, Puerto Rico, Louisiana, Arkansas, New York, and California. The panicle rice mite has the potential to cause major damage to the United States rice industry if it becomes established in commercial fields. We have begun to obtain population genetic data from the panicle rice mite in order to aid in identification, and detection so as to hinder the spread of the mite in the United States and minimize crop losses. This project will provide the basic scientific information necessary to lay the foundation for an effective biological control program before the mite becomes an uncontrollable pest. We sequenced the mitochondrial cytochrome oxidase subunit I (COI) for several U.S. populations of *S. spinki* and found that all COI sequences are identical, supporting the hypothesis that these infestations are very recent invasions into these research greenhouses, likely occurring around the same time period since they haven't had a chance to diverge yet.

INTRODUCTION

The panicle rice mite, *Steneotarsonemus spinki* Smiley, has been a serious pest of rice (*Oryza sativa*) across tropical Asia (Tseng, 1984) and was recently introduced to the Americas in the late 1990s. Since introduction, *S. spinki* has been responsible for crop losses ranging from 30% to 90% per year since introduction to the Caribbean and Central America (Almaguel et al., 2000).

The United States produces approximately 9 million metric tons of rice, worth roughly $2.5 billion, yearly and is one of the top five rice exporters worldwide. When in association with sheath rot fungus (*Sarocladium oryzae*), which it is thought to commonly vector among rice plants, losses and plant sterility are often greater than 70% (Chen et al., 1979). Damage caused by mite infestations and the vectored sheath rot fungus leads to deformation, yield loss, and sterility in rice plants. Discovery of the mite in 2008 in Puerto Rico, which provides seed to rice researchers and certain commercial seed companies, and in Louisiana, Arkansas, Texas, and recently California, sets up the United States rice industry for increased problems. Successful establishment of the mite in U.S. commercial rice fields could result in severe economic losses. Once established, the mite is very difficult to treat with conventional pesticides due to governmental regulations and where it resides in the plant. Additionally, many pest mites have shown abilities to quickly form resistance to pesticides, increasing the yearly expense for control and the hazards for producers and consumers. The ideal approach would be to effectively maintain a quarantine of this mite and prevent any of the greenhouse outbreaks from spreading to the production areas. Also, the intensive use of natural predators to control mite populations has potential to limit the problem if rice mites become established in rice growing areas.

Traditionally with invasive species, U.S. policy has dictated that a project is not worth funding until the invasive organism has reached pest status (e.g., Emerald Ash Borer, Red Fire Ants, Zebra Mussels). Unfortunately, once an invasive species becomes established and widespread it is often very difficult to control or eradicate. Additionally, most research on control programs take numerous years before any applicable procedures or treatments are ready for wide-scale field testing. Because of the early detection of this mite, we have the opportunity to get ahead in the game and develop control methods before the mite becomes established and causes major damage. The objective of this study was to determine the genetic diversity of U.S. rice panicle mite populations and compare them to foreign mite specimens to understand where U.S. populations came from. A subsequent objective of this study is to develop molecular detection tools for rapid and conclusive identification of the pest and to assist quarantine efforts in preventing infested seed lots (a suspected source of entry) from being imported to the U.S.

PROCEDURES

The identity of ethanol preserved rice panicle mite samples received from APHIS was confirmed by visual examination using a dissecting microscope. Representative mites from each sample were slide mounted and several individual mites from each sample were selected for DNA extraction. Mite DNA was extracted using the QIAamp DNA Micro Kit from (Qiagen Inc. Valencia, Calif.). The COI gene and ITS region was amplified using Platinum TAQ DNA polymerase (InvitrogenTM1, Carlsbad, Calif.)

with conditions described at the following web site (http://www.dnabarcoding.ca/pa/ge/research/protocols/amplification). COI primers were HCOI 5'-TAAACTTCAGGGTGACCAAAAAATCA-3' and LCOI 5'- GGTCAACAAATCATAAAGATATTGG-3'. COI PCR conditions were as follows: 1) 94 °C 3 min, 2) 94 °C 30 sec, 3) 45 °C 40 sec, 4) 72 °C 1 min, 5) Goto 2 4 times, 6) 94 °C 30 sec, 7) 51 °C 40 sec, 8) 72 °C 1 min, 9) Goto 6 34 times, 10) 72 °C 10 min, and 11) 4 °C. The ITS sequences were amplified using primers ITS-318SF 5'-AGAGGAAGTAAAAGTCGTAACAAG-3', ITS-528SR 5'-ATATBCTTAAATTCAGGGGG-3'. The ITS PCR conditions were as follows: 1) 95 °C 5 min, 2) 95 °C 30 sec, 3) 48 °C 30 sec, 4) 72 °C 3 min, 5) Goto 2 35 times, 6) 72 °C 10 min, and 7) 4 °C. PCR amplified DNA samples were analyzed on a 1% agarose gel and stained with GelRedTM (Biotium Inc. Hayward, Calif.). PCR products were purified using the QIA-quick PCR Purification Kit (Qiagen Inc., Valencia, Calif.). PCR products were sequenced by Macrogen Inc. (Rockville, Md.) and sequences were analyzed using Vector NTI software (InvitrogenTM1, Carlsbad, Calif.). PCR products that amplified only weakly were ligated into the pGem T easy vector using the standard TA cloning produre (Promega Inc., Madison, Wis.). Successful ligation events were determined by blue-white selection. White colonies, putative transformants, were further screened for positive transformants using PCR. Two bacterial transformants for every PCR product were grown under selection in Luria Broth and pGem T easy plasmid with PCR insert was purified using the QIAprep Spin Miniprep Kit (Qiagen Inc., Valencia, Calif.). The purified plasmids were sequence and analyzed, as described above.

RESULTS AND DISCUSSION

We began work on this project in April 2008 to determine the genetic diversity, occurrence, and mode of dispersal of the panicle rice mite (*Steneotarsonemus spinki*) in the rice-growing area of Arkansas. Our initial objective was to determine the genetic diversity of the panicle rice mite, as other objectives are dependent on this.

Extracting a sufficient quantity of DNA from an individual microscopic panicle rice mite for PCR amplification is technically challenging. Previously to this project, we used the DNeasy kit from Qiagen for other mite species, but switched to the DNA Micro Kit for the especially small panicle rice mite and found it to be superior. We then tested the effect of freezing the panicle mite in the kits suspension buffer, as other researchers reported that this improved DNA yield. No improvement in PCR amplification was observed in our hands. We also found that the addition of trehalose to the PCR reaction mixture improved PCR amplification over the standard PCR conditions using Invitrogen's Platinum TAQ. This protocol was developed by the Canadian Centre for DNA Barcoding and is published on their website (http://www.dnabarcoding.ca/pa/ge/research/protocols/amplification).

We have extracted and sequenced the mitochondrial cytochrome oxidase subunit I (COI) for numerous U.S. populations of *S. spinki* collected from 2007 to 2009. Specimens from 2007 came from a Cornell greenhouse (N.Y.); Rice Tec, Inc. (Houston, Texas); a Texas research greenhouse, and LSU research fields (La.). Specimens from

2008 were obtained via USDA, APHIS Inland Inspection (Austin, Texas) from locations in New York (Cornell University Greenhouse), Arkansas (Dale Bumpers National Rice Research Center), and Texas (Rice Tec, Inc.). Specimens from 2009 were again from Texas (Rice Tec, Inc.). All samples obtained to date have been extracted and all successful extractions have been amplified and sequenced. Cytochrome oxidase I (COI) was the gene of choice for this study because of its high copy number, fast mutation rate, and a comparatively small variance within species making it an excellent candidate for molecular diagnostics as well as for the analysis of genetic diversity. Multiple COI sequences have been obtained for *S. spinki* from all locations previously mentioned and results have indicated that all posses identical COI sequences.

We have also sequenced COI for *Tarsonemus bilobatus* found in rice from a research field at LSU collected in 2007. *T. bilobatus* is another mite commonly found in rice plants and we need these sequences to distinguish them from the panicle rice mite sequences. This is especially useful for the purpose of molecular diagnostics. We will continue to receive and analyze other rice associated specimens in order to distinguish all possible species from PRM.

Attempts to sequence ITS, a quickly evolving nuclear gene, mostly failed. Direct amplification techniques through PCR failed to produce enough useable sequences even after all variables and parameters were exhausted. This gene has been known to be difficult to sequence in some animals, but is also more variable than COI and worth the effort. Attempts to clone the ITS region from the panicle mite resulted in positive colony growth. Unfortunately, all sequences were from fungi rather than mites. We are currently trying to figure out the problem with ITS and may employ one more tactic to obtain the data.

To date, confirmed panicle rice mites have been collected from Arkansas, Louisiana, Texas, and New York. We have also received mites from China and have been in contact with researchers in numerous Latin American countries; however, none of these contacts have resulted in actual specimens. We are continuing to pursue panicle rice mite DNA from Latin America and other rice-growing regions in the world.

In order to further characterize the genetic diversity of rice panicle mites we will require sequences from many international regions and must be able to amplify and sequence another gene region such as ITS. Until we can obtain these additional mite samples, the project cannot progress.

SIGNIFICANCE OF FINDINGS

These findings lead to a few preliminary conclusions. First, this likely indicates that these are very recent invasions into these research greenhouses, likely occurring around the same time period since they haven't had a chance to diverge yet. This contradicts the belief that this mite is a common pest of no importance around since at least the 1960s. If this were the case we would expect to see significant divergence between these populations. Additionally, we would expect to find specimens outside of research greenhouses and plots. Also, panicle rice mites often reproduce parthenogenetically, so it is possible that using a maternally inherited gene like COI may have confounded the results, but many asexual mite groups still show COI divergence across populations, so we do not feel that this is necessarily the case. Either way, sequencing of a nuclear gene will shed more light on the situation. We cannot make any claims as to where this mite came from at this point because we have not yet obtained specimens from any localities outside the United States. We have contacted numerous international researchers in order to obtain PRM, but to this point have been unsuccessful. A colleague at the USDA is also contacting international colleagues on our behalf.

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PEST MANAGEMENT: INSECTS

Comparison of Various Insecticide Seed Treatments to Foliar Insecticide Application for Control of Rice Water Weevil [*Lissorhoptrus oryzophilus* (Kuschel)]

J.E. Howard and D.S. Akin

ABSTRACT

A trial was conducted at the University of Arkansas Southeast Research Station near Rohwer, Ark., in 2009 to evaluate the efficacy of two rates of a chlorantraniliprole insecticide seed treatment and a single rate of a thiamethoxam insecticide seed treatment in comparison to a foliar insecticide application of lambda-cyhalothrin for control of rice water weevil. No differences were observed among treatments in plant stand counts or plant heights. However, significant differences were noted in the number of rice water weevil larvae per 5 cores in samples collected. Most seed treatments showed significantly better control of rice water weevil when compared to the untreated check as well as improving control in comparison to the foliar insecticide treatment. Yield data were collected and analyzed but were excluded from this report due to the variability resulting from conditions at harvest.

INTRODUCTION

The rice water weevil (*Lissorhoptrus oryzophilus*) (RWW) has proven to be a destructive pest in rice, being one of the primary pests of rice in Arkansas (Gianessi et al., 2009). The adult is about 0.125-in. (3 mm) long, brown with olive gray areas and with dark (almost black) areas on the thorax and elytra (wing covers). The proboscis is short and stout and about as long as the thorax. The larvae are white, legless, ca. 0.25 in. (8 mm) long and have a brown head. Each abdominal segment (2 through 7) has a pair of dorsal hooks on small projections. Oviposition is stimulated by the presence of submerged plants. Eggs are deposited in the leaf sheath below the water surface (Lorenz et al., 2006). Adult feeding damage to developing leaf tissue is rarely of economic importance. However, larval damage to developing plant roots can reduce plant vigor and yields by interfering with the ability of the plant to take up nutrients and water. Severely damaged plants also are more prone to wind damage because the pruned roots no longer provide anchorage to the soil (Boyd and House, 2001).

While RWW adults are susceptible to many foliar insecticides, achieving control with this strategy has proven to be somewhat variable as scouting for the adults and subsequently timing the foliar application to coincide with their presence in the field is difficult.

PROCEDURES

This trial was conducted in 2009 at the University of Arkansas Southeast Research Station near Rohwer, Ark. Plots were 9-ft wide × 20-ft long, and arranged in a randomized complete block design with four replications. 'Wells' variety was used and planted at 80 lb/acre on 1 May 2009. Treatments included Dermacor X-100 (Rynaxypyr®, DuPont de Nemours and Company, Wilmington, Del.) at 0.071 and 0.101 lb ai/acre, Cruiser (thiamethoxam, Syngenta Crop Protection, Wilmington, Del.) at 3.3 fl oz/cwt, a foliar application 3 days pre-flood of Karate Zeon® (lambda-cyhalothrin, Syngenta Crop Protection, Wilmington, Del.) at 2.56 fl oz/acre, and an untreated check. The foliar application was made 3 days prior to establishment of permanent flood in an attempt to control adults entering the field for oviposition. At 2 weeks after emergence, stand counts were obtained by counting the number of plants in 79 in. (2 m) of a drilled row (Table 1). At 4 weeks after flood, larval counts were made by collecting five 4-in. cores per plot. Cores were soaked and washed to remove all larvae from the samples using a 40-mesh sieve. Individual samples were then submerged in a low salt solution to allow the larvae to float to the surface for counts. The totals from the five sub-samples were then combined for each plot and analyzed (Table 2). Plant heights were collected prior to harvest across 10 sample points and averaged (Table 3). Data were analyzed using Agriculture Research Manager Version 8 (Gylling Data Mgt, Brookings, S.D.), using AOV and Duncan's New Multiple Range Test ($\alpha = 0.05$) for means separation.

RESULTS AND DISCUSSION

It should be noted that within the first week of permanent flood being established, water was lost over the entire trial area due to a broken levee. Said levee was repaired and the trial was re-flooded within a few days. While no significant differences were noted among treatments in stand counts (Table 1) or plant heights (Table 3), the RWW larva totals did show significant differences among most treatments (Table 2). Analysis showed RWW larva totals in the foliar Karate Zeon® treatment did not statistically differ from the untreated check. This suggests that either the application of the foliar insecticide was mistimed, or the residual activity of the foliar insecticide was ineffective in controlling adults prior to oviposition. Cruiser® did not provide significantly better control than either the untreated check or the foliar insecticide treatment in this particular case. Conversely, both rates of Dermacor® provided significantly better control than the foliar Karate Zeon® treatment and the untreated check. The low rate (0.071 lb ai/acre) of Dermacor® provided statistically similar control as the high rate (0.101 lb ai/acre) of Dermacor® and the Cruiser® treatment. However, the high rate of Dermacor® provided significantly better control than Cruiser® in this trial with respect to RWW larval density. Yield data were collected for this trial by plot combine, but because of the heavily saturated condition of the field, the harvest process was not consistent and yield data were unreliable.

SIGNIFICANCE OF FINDINGS

Because achieving control of rice water weevil adults prior to egg lay with a foliar insecticide has at times proven to be difficult, utilizing seed treatments for control is a more consistent alternative for RWW control. Though the scope of this experiment did not encompass all available insecticide seed treatments for RWW, two of the seed treatments tested did achieve effective control of the RWW in this trial.

ACKNOWLEDGMENTS

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Table 1. Stand counts at 2 weeks post-emergence for seed treatments, foliar insecticides, and untreated check.

Treatments	Number of plants
	[no./79 in. (2 m)]
Untreated check	61 a[z]
Dermacor X-100 0.071 lb ai/acre	67 a
Dermacor X-100 0.101 lb ai/acre	68 a
Cruiser 3.3 fl oz/cwt	61 a
Karate Zeon 2.56 fl oz/acre	61 a

[z] Means not followed by the same letter are not significantly different (Agronomic Research Manager, Duncan's New MRT α = 0.05).

Table 2. Rice water weevil larvae found in 5 core samples per plot for seed treatments, foliar insecticides, and untreated check.

Treatments	Rice water weevil larvae
	(no./5 cores)
Untreated check	22 a[z]
Dermacor X-100 0.071 lb ai/acre	8 bc
Dermacor X-100 0.101 lb ai/acre	4 c
Cruiser 3.3 fl oz/cwt	15 ab
Karate Zeon 2.56 fl oz/acre (foliar)	25 a

[z] Means not followed by the same letter are not significantly different (Agronomic Research Manager, Duncan's New MRT α = 0.05).

Table 3. Pre-harvest plant heights for seed treatments, foliar insecticides, and untreated check.

Treatments	Plant height
	[in. (cm)]
Untreated check	44.5 (113) a[z]
Dermacor X-100 0.071 lb ai/acre	45.3 (115) a
Dermacor X-100 0.101 lb ai/acre	46.1 (117) a
Cruiser 3.3 fl oz/cwt	46.5 (118) a
Karate Zeon 2.56 fl oz/acre	47.2 (120) a

[z] Means not followed by the same letter are not significantly different (Agronomic Research Manager, Duncan's New MRT α = 0.05).

Comparing the Efficacy of Insecticide Seed Treatments at Three Seeding Rates

H. Wilf, G. Lorenz III, K. Colwell, and N. Taillon

ABSTRACT

Trials were conducted at four locations in Arkansas during 2009 to evaluate the efficacy of selected insecticide seed treatments including: Cruiser (thiamethoxam), Dermacor (rynaxapyr), and Nipsit Inside (clothianidin); for control of grape colaspis (*Coleoptera: Chrysomelidae*) (GC) and rice water weevil (*Coleoptera: Curculionidae*) (RWW) at three seeding rates of 60, 90, and 120 lb/acre. Seed treatments generally increased stand count compared to untreated check. Cruiser and Nipsit Inside controlled grape colaspis at the lowest seeding rate. All seed treatments proved to be effective for RWW control at all seeding rates. In most cases, the seed treatments increased yield over the untreated check.

INTRODUCTION

An important pest in Arkansas rice fields is the GC also known as the lespedeza worm. The GC is a threat primarily to the rice growers of the Grand Prairie and White River regions of the state; however it can be problematic in other rice-growing areas. Adults are about 0.1875 in. long, oval, golden brown in color and the elytra (wing covers) have rows of longitudinal ridges. The small grubs are white to tan in color with a brown head. Larvae eat away at the rice stem and roots causing a "girdling" effect, which causes the plant to yellow and become stunted and, in many cases, can cause significant stand reduction (Lorenz et al., 2006). Fields most likely to sustain injury from grape colaspis are those that were planted in corn or soybeans the previous year (Thomas et al., 2009). High densities of GC larvae can lead to a significant stand loss resulting in a year-end yield reduction (Lorenz et al., 2006). Thin stands caused by GC often result in increased RWW infestations that are attracted to areas in the field with a thin stand.

Rice water weevils are estimated to be present in more than 90% of the rice fields throughout the southern states every year (Gianessi et al., 2009). The RWW overwinters as an adult in accumulated leaf litter in well-drained, wooded or grassy areas and any other sheltered areas near rice fields. The RWW adults fly into fields in early spring when fields are flooded and begin feeding on rice leaves. This feeding is characterized by long linear scars. While the feeding scars signal infestation of RWW in the field they do not result in any significant damage. Female RWW will not lay their eggs until fields have been flooded. Once the field has been flooded, the female RWW swims from plant to plant and deposits eggs in the leaf sheaths below the water surface. Eggs are usually laid 1 to 2 weeks after flooding. The hatching period usually occurs 4 to 9 days after the egg has been laid. Newly hatched larvae feed in the leaf sheath for a few days and then sink into the soil surface and begin feeding on the rice roots. The larval stage is considered the damaging stage of the RWW (Lorenz et al., 2006). When the rice root system is damaged by larval feeding, the plant's uptake of nutrients is reduced and nutrient deficiency symptoms may occur (Bernhardt et al., 2001). Severely damaged plants become yellow and stunted and will have delayed maturity resulting in a stand loss and yield reduction. Occasionally root pruning will be so severe, plants cannot remain anchored in the soil.

PROCEDURES

Trials were conducted in 2009 in Poinsett, St. Francis, Prairie, and Lonoke counties. Plot size was 5-ft × 25-ft in a randomized complete block design with four replications. The rice variety 'Wells' was used in all studies. All treatments received a fungicide seed treatment including Apron XL, Maxim, and Dynasty. Seeding rates include 60, 90, and 120 lb seed/acre. Insecticide seed treatments were Cruiser 3.3 oz/cwt, Dermacor 1.75 oz/cwt, and NipsIt Inside 1.92 oz/cwt. A randomized stand count and average plant height was collected 2 to 3 weeks after planting by counting plants in 10-row ft./plot, and plant heights by measuring average height of 10 plants/plot.

Grape colaspis and rice water weevil larvae were evaluated by taking 4 core samples/plot with a 4-in. cylinder core sampler. Grape colaspis samples were collected 3 to 4 weeks postemergence and RWW samples were collected 3 weeks post flood. All samples were processed at the University of Arkansas Division of Agriculture Lonoke Extension and Applied Research Center, using a wash technique to remove and capture all larvae from the soil and roots using a 40- gauge mesh sieve. Samples were then put in a salt solution to allow larvae to float to the top for an accurate count. Data were processed using Agriculture Research Manager Version 8, AOV, and Duncan's New Multiple Range Test (P = 0.10) to separate means.

RESULTS AND DISCUSSION

Stand counts indicated that the untreated check (60 lb/acre), Cruiser (60 lb/acre), and NipsIt Inside (60 lb/acre) had a significantly higher stand count than Dermacor (60 lb/acre) (Table 1). At the 90 lb seeding rate, Cruiser, Dermacor, and NipsIt Inside had a significantly higher stand count than the untreated check. At the 120 lb seeding rate, NipsIt Inside had a significantly higher stand count than the untreated check. All seeding rates regardless of insecticide seed treatments were significantly different, with the 120 lb seeding rate having the highest stand count and the 60 lb/acre seeding rate having the lowest stand count (Table 1).

Grape colaspis counts at the St. Francis County location indicated that Cruiser (60 lb/acre) and NipsIt Inside (60 lb/acre) had significantly fewer grape colaspis larvae than the untreated check (60 lb/acre). All treatments with a 90 and 120 lb/acre seeding rate had no significant differences for control of grape colaspis (Table 2).

Rice water weevil counts pooled across locations indicated that all seed treatments had significantly fewer weevil larvae than the untreated check regardless of the seeding rate (Table 3).

Cruiser at the 60 lb/acre seeding rate had a higher yield than all other treatments. At the 90 lb/acre seeding rate Dermacor and NipsIt Inside had higher yields than the Cruiser. At the 120 lb/acre seeding rate all treatments had a higher yield than the untreated check (Table 4). It is interesting to note that the yield of Cruiser plots did not differ significantly across all seeding rates, while higher seeding rates appeared to enhance yield for Dermacor and NipsIt Inside.

SIGNIFICANCE OF FINDINGS

Insecticide seed treatments did appear to increase stand counts at some seeding rates indicating that growers may be able to reduce seeding rates with the use of these products. Grape colaspis control was achieved with both Cruiser and Nipsit Inside and all seed treatments were effective for control of rice water weevil. Also, there was a trend for higher yields with the seed treatments compared to the untreated check.

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Table 1. Across location summary of plant stand counts, data was collected by counting plants in 10 row feet per plot.

Treatment	Seeding rate	Stand count
		(no/10 row-ft)
Untreated check	60 lb/acre	89 e
Cruiser 3.3 oz/cwt	60 lb/acre	93 e
Dermacor 1.75 oz/cwt	60 lb/acre	81 f
NipsIt Inside 1.92 oz/cwt	60 lb/acre	89 e
Untreated check	90 lb/acre	106 d
Cruiser 3.3 oz/cwt	90 lb/acre	118 c
Dermacor 1.75 oz/cwt	90 lb/acre	121 c
NipsIt Inside 1.92 oz/cwt	90 lb/acre	119 c
Untreated check	120 lb/acre	137 b
Cruiser 3.3 oz/cwt	120 lb/acre	140 ab
Dermacor 1.75 oz/cwt	120 lb/acre	143 ab
NipsIt Inside 1.92 oz/cwt	120 lb/acre	146 a

Table 2. Grape colaspis larvae found in 4 cores samples per plot at the Pine Tree Research Station, St. Francis County, Ark. All of the core samples were taken at 3 to 4 weeks post emergence.

Treatments	Seeding rate	Grape colaspis
Untreated check	60 lb/acre	19 a
Cruiser 3.3 oz/cwt	60 lb/acre	4 b
Dermacor 1.75 oz/cwt	60 lb/acre	12 ab
NipsIt Inside 1.92 oz/cwt	60 lb/acre	4 b
Untreated check	90 lb/acre	6 b
Cruiser 3.3 oz/cwt	90 lb/acre	7 b
Dermacor 1.75 oz/cwt	90 lb/acre	4 b
NipsIt Inside 1.92 oz/cwt	90 lb/acre	5 b
Untreated check	120 lb/acre	11 ab
Cruiser 3.3 oz/cwt	120 lb/acre	4 b
Dermacor 1.75 oz/cwt	120 lb/acre	8 b
NipsIt Inside 1.92 oz/cwt	120 lb/acre	6 b

Table 3. Across location rice water weevil larvae summary, larvae found in 4 cores samples per plot. All of the core samples were taken 3 weeks after permanent flood.

Treatment	Seeding rate	Rice water weevil
Untreated check	(60 lb/acre)	20 a
Cruiser 3.3 oz/cwt	(60 lb/acre)	8 cd
Dermacor 1.75 oz/cwt	(60 lb/acre)	8 de
NipsIt Inside 1.92 oz/cwt	(60 lb/acre)	10 c
Untreated check	(90 lb/acre)	16 b
Cruiser 3.3 oz/cwt	(90 lb/acre)	8 cd
Dermacor 1.75 oz/cwt	(90 lb/acre)	8 cd
NipsIt Inside 1.92 oz/cwt	(90 lb/acre)	8 cd
Untreated check	(120 lb/acre)	21 a
Cruiser 3.3 oz/cwt	(120 lb/acre)	6 de
Dermacor 1.75 oz/cwt	(120 lb/acre)	7 de
NipsIt Inside 1.92 oz/cwt	(120 lb/acre)	6 de

PEST MANAGEMENT: INSECTS

Efficacy of Selected Insecticide Seed Treatments for Control of Grape Colaspis and Rice Water Weevil

H. Wilf, G. Lorenz III, K. Colwell, and N. Taillon

ABSTRACT

Trials were conducted at four locations in Arkansas during 2009 to evaluate the efficacy of selected insecticide seed treatments including thiamethoxam (Cruiser), clothianidin (NipSit Inside), and rynaxapyr (Dermacor), for control of grape colaspis (*Coleoptera: Chrysomelidae*) (GC) and rice water weevil (*Coleoptera: Curculionidae*) (RWW). Results indicated that the seed treatments increased stand counts and all products were very effective for controlling rice water weevil, while grape colaspis control was somewhat variable.

INTRODUCTION

Arkansas ranks first among the six major rice-producing states, accounting for approximately 48% of the U.S. rice production, producing roughly 1.3 million acres each year (USA Rice Federation, 2009). Arguably the most important insect pest in Arkansas rice production is the grape colaspis, also known as the "lespedeza worm". This particular pest is well-known for its early season presence and detrimental effects to stand establishment. The GC is known to be a threat primarily to the rice growers of the Grand Prairie and White River regions of the state, however it can be problematic in other rice-growing areas of the state. Adults are about 0.1875 in. long, oval, golden brown in color, and the elytra (wing covers) have rows of longitudinal ridges. The small grubs are white to tan in color with a brown head. Larvae eat away at the rice stem and roots causing a "girdling" effect, which causes the plant to yellow and become stunted and, in many cases, can cause significant stand reduction (Lorenz et al., 2006). Fields most likely to sustain injury from grape colaspis are those that were planted in corn or soybeans the previous year (Thomas et al., 2009). Often times early season reduction of stands in the field caused by the GC can attract RWW to come into a field after the flood has been applied.

Rice water weevils are estimated to be present in more than 90% of the rice fields in southern states every year (Gianessi et al., 2009). The RWW overwinters as an adult in accumulated leaf litter in well-drained, wooded or grassy areas and any other sheltered areas near rice fields. The RWW adults fly into fields in early spring and begin feeding on rice leaves. This feeding is characterized by long linear scars. These scars signal detection that the RWW adults are present in the field but do not cause any significant damage. Female RWW do not lay their eggs until fields have been flooded. Once the field has been flooded, the female RWW swims from plant to plant and deposits eggs in the leaf sheaths below the water surface. Eggs are usually laid 1 to 2 weeks after flooding. The hatching period usually occurs 4 to 9 days after the egg has been laid. Newly hatched larvae feed in the leaf sheath for a few days and then sink into the soil surface and begin feeding on the rice roots. The larval stage is considered the damaging stage of the RWW (Lorenz et al., 2006). When the rice root system is damaged by larval feeding, the plant's uptake of nutrients is reduced and nutrient deficiency symptoms may occur (Bernhardt et al., 2001). Severely damaged plants become yellow and stunted and will have delayed maturity resulting in a stand loss and yield reduction. Occasionally root pruning will be so severe, plants cannot remain anchored in the soil. The larvae are tiny in size but grow quickly through four larval stages in four weeks. When RWW larvae become fully grown they build a water tight, oval mud cell in which they pupate and later become adults (Lorenz et al., 2006).

PROCEDURES

Trials were conducted in 2009 in Poinsett, St. Francis, and Prairie counties. Plot size was 5-ft × 25-ft in a randomized complete block design with four replications. The rice variety 'Wells' was used in all studies and all the treatments were treated with a fungicide package including Apron XL, Dynasty, and Maxim. A seeding rate of 80 lb seed/acre was used at all locations. Insecticide seed treatments were Dermacor X-100 at 1.53 oz/cwt, 1.66 oz/cwt, 2.2 oz/cwt, HGW86 2.2 oz/cwt, 3.12 oz/cwt, Karate Z (Foliar 3-5 DPF) 2.56 fl oz/acre, NipsIt Inside 1.92 oz/cwt, Cruiser 3.3 oz/cwt, and Aeris 6.4 oz/cwt. Stand count and plant height data were collected 2 to 3 weeks after planting by counting plants in 10 row-ft/plot, and plant heights by measuring average height of 10 plants/plot. Grape colaspis and RWW larval counts were taken with a 4-inch cylinder core sampler (4 core samples per plot). The GC samples were collected 3 to 4 weeks post emergence and RWW samples were collected 3 weeks post flood. All samples were processed at the University of Arkansas Division of Agriculture Lonoke Extension and Applied Research Center, using a wash technique to capture all larvae from the soil and roots using a 40-gauge mesh sieve. Samples were then put in a salt solution to allow all larvae to float to the top for an accurate count. Data were processed using Agriculture Research Manager Version 8, AOV, and Duncan's New Multiple Range Test (P = 0.10) to separate means.

RESULTS AND DISCUSSION

Plant stand counts indicated that the Dermacor (2.2 oz), HGW86 (3.12 oz), NipsIt Inside, and Aeris had significantly higher stand counts than the untreated check, Dermacor (1.66 oz), HGW86 (2.2 oz), Karate, and Cruiser (Table 1). Grape colaspis counts at the St. Francis County location indicated that HGW86 (3.12 oz), NipsIt Inside, Cruiser, and Aeris treatments significantly reduced GC numbers compared to the untreated check and all other treatments (Table 2). Rice water weevil counts indicated that all treatments had significantly fewer weevil larvae than the untreated check and Karate Z (Foliar 3-5 DPF) 2.56 fl oz/acre (Table 3). Yield across trials indicated that HGW86 2.2 oz and 3.12 oz, and NipsIt Inside had higher yields than the untreated check and all other treatments (Table 4).

SIGNIFICANCE OF FINDINGS

The insecticide seed treatment trials indicated that these products provided excellent control of RWW. The trials also indicated that Cruiser and NipsIt Inside provided significantly better control for GC than Dermacor. It appears that seed treatments may be the best means for control of these pests.

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The authors would like to thank our rice producers: Barry Huber, Blake Swears, Dennis Price, Dustin Engler, Greg Jones, Jimmy Price, Mike Medford, and Shawn Clark at the Pine Tree Research Station for their cooperation. These studies were supported by Rice Check-Off funds. Also we acknowledge DuPont, Syngenta, and Valent, for their support.

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Table 1. Across location summary of plant stand counts, data was collected by counting plants in 10 row feet per plot.

Treatments	Stand count
	(no./10 row-ft)
Untreated check	113 cd
Dermacor X-100 1.53 oz/cwt	118 bcd
Dermacor X-100 1.66 oz/cwt	112 d
Dermacor X-100 2.2 oz/cwt	120 ab
HGW86 2.2 oz/cwt	114 cd
HGW86 3.12 oz/cwt	121 ab
Karate Z (Foliar 3-5 DPF) 2.56 fl oz/acre	106 e
Nipsit Inside 1.92 oz/cwt	125 a
Cruiser 3.3 oz/cwt	118 bc
Aeris 6.4 oz/cwt	124 a

Table 2. Grape colaspis larvae found in 4 cores samples per plot at the Pine Tree Research Station, St. Francis County, Ark. All of the core samples were taken at 3 to 4 weeks post emergence.

Treatment	Grape colaspis
Untreated Check	12 a
Dermacor X-100 1.53 oz/cwt	6 a-d
Dermacor X-100 1.66 oz/cwt	9 abc
Dermacor X-100 2.2 oz/cwt	11 ab
HGW86 2.2 oz/cwt	7 a-d
HGW86 3.12 oz/cwt	5 bcd
Karate Z (Foliar 3-5 DPF) 2.56 fl oz/acre	7 a-d
Nipsit Inside 1.92 oz/cwt	4 cd
Cruiser 3.3 oz/cwt	2 d
Aeris 6.4 oz/cwt	1 d

Table 3. Across location rice water weevil larvae summary, larvae found in 4 cores samples per plot. All of the core samples were taken at 3 weeks after permanent flood.

Treatment	Rice water weevil
Untreated check	25 a
Dermacor X-100 1.53 oz/cwt	6 b
Dermacor X-100 1.66 oz/cwt	3 b
Dermacor X-100 2.2 oz/cwt	5 b
HGW86 2.2 oz/cwt	6 b
HGW86 3.12 oz/cwt	6 b
Karate Z (Foliar 3-5 DPF) 2.56 fl oz/acre	30 a
Nipsit Inside 1.92 oz/cwt	6 b
Cruiser 3.3 oz/cwt	8 b
Aeris 6.4 oz/cwt	7 b

Table 4. Across location harvest summary (seeding rate), Lake Hogue (Poinsett County), Price Bros. Farm (Prairie County), and Swears Farm (Lonoke County) harvest totals, 2009.

Treatment	Yield
	(bu/acre)
Untreated check	175 c
Dermacor X-100 1.53 oz/cwt	180 bc
Dermacor X-100 1.66 oz/cwt	175 c
Dermacor X-100 2.2 oz/cwt	176 c
HGW86 2.2 oz/cwt	183 ab
HGW86 3.12 oz/cwt	188 ab
Karate Z (Foliar 3-5 DPF) 2.56 fl oz/acre	176 c
Nipsit Inside 1.92 oz/cwt	188 ab
Cruiser 3.3 oz/cwt	182 abc
Aeris 6.4 oz/cwt	182 abc

PEST MANAGEMENT: WEEDS

Effects of Low Rates of Glyphosate and Glufosinate on Rice

B.M. Davis, R.C. Scott, J.K. Norsworthy, and K.L. Smith

ABSTRACT

Off-target movement of herbicides have been detrimental to crop yields. When new technology is released, it is necessary to understand the potential impact it may have on off-target crops. Field studies were conducted in 2007 and 2008 to evaluate and compare the effects of low rates of glufosinate and glyphosate on rice. Glyphosate (1× rate = 0.77 lb/acre) and glufosinate (1× rate = 0.55 lb/acre) were applied to rice at 0.5×, 0.25×, and 0.125× of the recommended usage rate at the 3- to 4-leaf, panicle initiation (PI), and boot growth stages. At comparable rates, glufosinate caused substantially greater visual injury than glyphosate to rice. Rice grain yield was reduced up to 80% with either herbicide. Because glyphosate is more readily translocated, overall sensitivity of off-target crops may be higher to lower rates or "drift rates" of glyphosate than glufosinate. However, because of a perception that glufosinate damage is "cosmetic" and will not harm off-target crops as much as glyphosate, educational efforts are needed to demonstrate potential negative impacts of glufosinate to off-target crops.

INTRODUCTION

Glyphosate is the most popular non-selective herbicide on the market. With the wide adoption of glyphosate-tolerant soybean technology throughout the state, there is inevitably an increased risk of off-target movement of glyphosate onto rice. However with this heavy reliance on glyphosate, resistant weeds have evolved. With this increase in glyphosate-resistant weeds, a new technology is needed. The 2009 growing season marked the release of glufosinate-tolerant soybean, which allows the use of glufosinate in over-the-top applications throughout the soybean growing season. The potential for off-target movement from soybean to rice is possibly due to the production practices in Arkansas of growing both crops in close proximity to each other.

MATERIALS AND METHODS

Field experiments were conducted at the University of Arkansas at Pine Bluff research farm near Lonoke, Ark., in 2007 and 2008 to evaluate the effects of low rates of glyphosate and glufosinate on rice and to evaluate potential yield loss. Rice was planted on 15 May 2007, and 21 May 2008, at a seeding rate of 18.5 lb/acre for 'Wells' and 6 lb/acre for 'XP723'. The experimental area was field cultivated twice prior to planting. The soil type was a Calhoun silt loam with a pH of 4.8. Plots were maintained weed free with a preemergence application of clomazone at 0.06 lb/acre plus quinclorac at 0.05 lb/acre and a postemergence application of halosulfuron at 0.01 lb/acre plus quinclorac at 0.04 lb/acre.

Plot size was 5 ft wide and 20 ft long with 5 ft alleys between replications. The experimental design was a randomized complete block with a three-factor factorial treatment arrangement with four replications. Treatment factors were rice cultivar, herbicide, and application timing. The first factor was cultivar where Wells and XP723 were seeded. The second factor was herbicide. Herbicides were glufosinate applied at 0.071, 0.13, and 0.27 lb/acre and glyphosate applied at 0.10 , 0.19, and 0.39 lb/acre. In earlier research, significant injury to rice occurred at these glyphosate rates (Meier et al., 2006). The rates for each herbicide represent 0.5×, 0.25×, and 0.125× the usage rate. The third factor was application timing. An early postemergence treatment was applied to 3- to 4-leaf rice on 6 June 2007 and 18 June 2008; a mid-postemergence application at 0.25-in. internode (PI) on 3 July 2007 and 25 July 2008; and a late postemergence application at boot stage on 31 July 2007 and 23 August 2008. Treatments were applied with a CO_2-backpack sprayer calibrated to deliver 10 gal/acre using a four-nozzle, 5-ft spray boom, with DG110015 tips. An untreated check was included for each cultivar for comparison.

Injury was visually rated on a scale of 0% to 100% compared to the untreated check, with 0% being no injury and 100% being plant death. Injury was rated for chlorosis and stunting. Ratings were taken at 1 and 3 weeks after treatment (WAT). Heading dates were recorded when 50% of the rice heads had emerged. Flag leaf length was measured at 100% emergence of the flag leaf in the nontreated plots. Canopy height was determined at heading (50%) and at harvest. Plots were harvested for yield and test weight on 20 September 2007 and 27 October 2008, with a small-plot combine. Percentage germination was determined post harvest using steps similar to those previously described (Lovelace, 2000; Stoller and Wax, 1974; Taylorson, 1970). Grain weight per 100 seed per plot treatment was recorded post harvest. Data were subjected to analysis of variance using PROC GLM in SAS. Means were separated by Fisher's Least Significance Difference test at P = 0.05.

RESULTS AND DISCUSSION

Visual Injury

Injury mainly consisted of necrosis of leaf tissue from glufosinate and chlorosis of leaf tissue to no symptoms for glyphosate, depending on application timing. Similar symptoms have been reported for wheat (Deeds et al., 2006). Injury 1 WAT was minimal for glyphosate and peaked at only 14% (Table 1). Later application of glyphosate during the reproductive stages resulted in no visual injury. Injury at the later timings manifested in other parameters. Injury from glufosinate was significantly higher and peaked at 60% at the boot stages. Glufosinate visual injury was much more apparent than that of glyphosate consisting of necrotic leaves. Similar trends were observed in other research in rice with later timings of glyphosate having minimal injury compared to earlier (Ellis et al., 2003). Visual injury from glyphosate at the later application timings was not apparent until the rice began to head. Applications at the PI stage injured the young seed head which, when emerged, was malformed with smaller heads and curled seeds. Glufosinate symptoms were apparent and consisted of necrosis of the tissue that had come into contact with the herbicide. Applications at the boot stage did not malform seed heads as with glyphosate at the PI stage, but both herbicides ceased rice growth and did not allow the seed head to fully emerge from the sheath. This in turn caused many panicles to “rot” in the leaf sheath.

This data suggest that rice is more susceptible to visual injury from glufosinate than glyphosate. This could be due to the nature of the two herbicides behaviors in the plant. Glyphosate is readily translocated within the plant compared to glufosinate and what little symptoms show up are on newly emerging vegetation. In contrast, glufosinate is not as readily translocated within the plant and generally causes foliar burn as documented. This data also suggests that rice may show a slightly higher sensitivity to an early application with glyphosate and later application from glufosinate. Ellis and others also documented the greatest injury occurring from 0.05 lb/acre of glufosinate when applied to 2- to 3-leaf rice (Ellis et al., 2003). In general, glyphosate injury was minimal compared to glufosinate at this time.

Canopy Height

The only treatments that reduced canopy height at heading applied at the 3- to 4-leaf stage were glyphosate at the 0.25× and 0.5× rates where canopy height was reduced by 10% to 15% and glufosinate applied at the 0.5× rate by 10% (Table 2). All other 3- to 4-leaf applications did not reduce canopy height. Ellis et al. (2003) documented 50% and 5% height reductions from glyphosate and glufosinate applied at 2- to 3-leaf stage on rice. Both herbicides applied at the 0.5× rate at the PI stage reduced canopy height; however, glyphosate reduced canopy height 5% less than glufosinate, which reduced canopy height 23% at the 0.5× rate applied at the boot stage. Reduction in height from glufosinate at the boot stage was 23% and glyphosate was 18%. At panicle differentiation, Ellis et al. (2003) documented similar reduction in canopy height from glufosinate and glyphosate at higher rates with reduction ranging from 10% to 25%. Glyphosate reduced canopy height by ceasing growth and stunting plants, in contrast glufosinate reduced canopy height by complete desiccation of the upper portion of the canopy.

Glyphosate and glufosinate applied at the 3- to 4-leaf stage at the 0.125× and 0.25× rate did not reduce canopy height at harvest (Table 3). However, all other treatments significantly reduced canopy height at harvest. The greatest reduction from glufosinate (25%) occurred when applied at the 0.5× rate at the boot stage. Glyphosate reduced canopy height the greatest (29%) when applied at PI. There is a slight trend of greater canopy height reduction from both herbicides at later application timings at all rates. Rice at the PI application timing appeared to be slightly more sensitive to glyphosate than glufosinate. This could be partly explained by the fact that glyphosate is readily translocated and ceased growth and stunts plants at this application timing. In contrast, glufosinate desiccates crop canopy to reduce height, however, does not cease rice growth. At the boot application stage, the rice plant is close to ceasing growth and focusing all resources on seed fill, in turn little canopy height reduction is noted. Both herbicides responded similarly at the boot stage. Similarly Meier et al. (2006) noted similar rice canopy reductions from glyphosate applied at 0.08 lb/acre at the boot application stage. Conversely, Ellis documented 50% canopy height reduction when glyphosate was applied at the 2- to- 3 leaf stage, with only 5% reduction from glufosinate. He also noted canopy height reduction from 10% to 25% from glyphosate and glufosinate, respectively, applied at panicle initiation (Ellis et al., 2003). These contradictory results are indicative of the random nature of low rates of herbicides and may be explained by differences in environmental conditions or specific application timings.

Flag Leaf Length

Even though both herbicides reduced flag leaf length, the forms of reduction were much different (Table 4). Glyphosate is translocated readily within the plant and at the PI stage is translocated to the actively developing flag leaf (Vencill, 2002). In turn, the flag leaf slows growth and is stunted, emerging as a shortened leaf. Glufosinate, however, is not as readily translocated and is fairly immobile (Vencill, 2002). Therefore at PI, glufosinate does not affect the formation of the flag leaf as great as glyphosate. Glufosinate does cause necrosis of the flag leaf once emerged resulting in a reduction in photosynthetically active leaf area.

Days to Heading

Glufosinate delayed heading the greatest when applied at the boot stage (25 to 47 days) (Table 5). The greatest delay in heading occurred when glufosinate was applied at the 0.5× rate at the boot stage (47 days). The early (PI) and later (boot) reproductive stage applications appear to be more detrimental to delaying maturity than application at the vegetative stage with either herbicide. Meier et al. (2006) reported similar results with glyphosate applied at the boot stage, with heading delayed for ‘Bengal’ rice from 21 to 42 days depending on rate. This delay may be caused by the interruption of the growth of the young seed head. Glyphosate applied at the boot stage and PI stage at the 0.25× and 0.5× rates prevented the panicle from emerging from the sheath, in turn causing the seed head to rot before harvest. Glufosinate affected the seed head by completely desiccating the upper portion of the plant and not allowing the seed head to fully emerge. When glufosinate was applied at the 0.25× and 0.5× rates at the boot stage, seed heads never emerged and rotted within the leaf sheath. In contrast, others have observed a greater reduction in yields at the earlier rather than at the later reproductive timings, with yield losses as great as 95% from applications at jointing or PI (Deeds et al., 2006).

Seed Weight

The greatest reduction in seed weight on Wells occurred from the 0.25× rate applied at the PI and boot stages and the 0.5× rate applied at the boot stage with reductions ranging from 7% to 11% (Table 6). Seed weight reduction ranged from 12% to 14% with XP723 when either herbicide was applied at the 0.25× or 0.5× rate. These trends are similar to flag leaf length reductions and reduced seed weights observed from either herbicide applied at the higher rates and applied at the reproductive stages. Similar results have been documented with leaf removal significantly reducing rice yield (Counce et al., 1994). This is a possible explanation for the reduced seed weight observed and corresponding injury from application made during reproductive development.

Germination of Harvested Grain

There were no significant interactions among cultivar, rate, herbicide, or application timing for rice germination. Regardless of treatment, rice germination ranged from 97% to 99% (data not shown). Germination could possibly be lower if all seed were tested. Plots were harvested with a commercial combine, which provides a very clean, trash-free sample as small malformed seeds are discharged from the rear of the combine. Deeds et al. (2006) also documented no significant difference in germination of wheat when glyphosate was applied. Similarly, Ellis et al. (2003) documented no reduction in rice germination following sublethal glyphosate rates.

Yield

All treatments regardless of cultivar, herbicide, or application timing reduced rice yield when averaged across rate. Glufosinate had the greatest reduction in yield for both cultivars when applied at the boot stage (81%) (Table 7). Glufosinate applied at PI reduced yield of Wells and XP723 by 30%. Glyphosate reduced yields for both cultivars when applied at the boot stage by 80%. Similarly, others have noted rice yield reductions from glyphosate applied at boot, ranging from 87% to 97% (Kurtz and Street, 2003). When glyphosate was applied at PI, yield reductions ranged from

31% on Wells to 51% on XP723 (Table 7). Kurtz and Street (2003) documented similar results with rice response to glyphosate applied at PI resulting in yield reductions of 66%. The response was similar for glufosinate applied at PI and boot stages on both cultivars. Both cultivars also responded similarly to glyphosate applied at the boot stage; however, glyphosate applied at PI appeared to have a greater affect on XP723 than on Wells. Yield was reduced 20% more on XP723 than Wells. Based on the data, a varietal response to glyphosate may exist when applied at both the 3- to- 4 leaf and PI growth stages for XP723. Results also suggest that rice is more sensitive to later applications of either herbicide. Ellis et al. (2003) concluded that rice and corn were able to recover from glufosinate injury; however, they were unable to recover from glyphosate, suggesting a higher sensitivity to glyphosate. Koger et al. (2005) reported a possible varietal difference in rice yield between 'Priscilla' and 'Cocodrie' rice cultivars. Though very minimal injury was noted for glyphosate, yield reductions were similar to those from glufosinate.

Rice yield losses reflect similar trends seen in several other parameters documented, such as flag leaf length, days to maturity, and seed weight. Later applications, after the vegetative stages, with higher rates are very detrimental to rice yields, regardless of herbicide.

SIGNIFICANCE OF FINDINGS

Glufosinate injured rice rapidly and to a greater degree than did glyphosate. Glyphosate caused very minimal injury, however yield reduction caused by the two herbicides was comparable. Flag leaf length was reduced by both herbicides. However, where glufosinate caused rapid necrosis of the flag leaf and upper portion of the plant when applied at the boot stage, glyphosate (which is more readily translocated to points of active cell division) caused flag leaf reductions when applied at PI, before the flag leaf had emerged.

In general, visual glyphosate injury was minimal when compared to glufosinate. However, yield reductions from both herbicides were comparable at the rates evaluated. Glufosinate drift to rice does have the potential to be detrimental to yield.

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Table 1. Interaction of herbicide and application timing on rice injury one week after treatment, averaged across rates and cultivars.

	Percent visual injury	
Application timing	Glufosinate	Glyphosate
3- to 4-leaf	53	14
Panicle initiation	53	3
Boot	60	1
LSD (0.05)	3	

Table 2. Interaction of herbicide (glufosinate and glyphosate), rate (0.125×, 0.25×, and 0.5× labeled rate), and application timing on rice canopy height at heading as a percent of nontreated check, averaged across cultivars.[z]

	Canopy height at heading					
	Glufosinate			Glyphosate		
Application timing	0.125	0.25	0.5	0.125	0.25	0.5
	(% of check)					
3- to 4-leaf	98	97	90	96	90	85
Panicle initiation	92	81	76	90	75	60
Boot	89	83	77	86	82	82
LSD (0.05)	5					

[z] Glufosinate rate based on 0.55 lb/acre label rate, glyphosate rate based on 0.77 lb/acre label rate.

Table 3. Interaction of herbicide (glufosinate and glyphosate), rate (0.125×, 0.25×, and 0.5× labeled rate), and application timing interaction on rice canopy height at harvest averaged across cultivars.[z]

	Canopy height at harvest					
	Glufosinate			Glyphosate		
Application timing	0.125	0.25	0.5	0.125	0.25	0.5
	(% of check)					
3- to 4-leaf	99	97	93	98	95	89
Panicle initiation	93	88	85	94	80	71
Boot	93	83	75	87	81	78
LSD (0.05)	3					

[z] Glufosinate rate based on 0.55 lb/acre label rate, glyphosate rate based on 0.77 lb/acre label rate.

Table 4. Interaction of herbicide (glufosinate and glyphosate), rate (0.125×, 0.25×, and 0.5× labeled rate), and application timing on rice flag leaf length as percent of nontreated check, averaged across cultivars.[z]

	Rice flag leaf length					
	Glufosinate			Glyphosate		
Application timing	0.125	0.25	0.5	0.125	0.25	0.5
	(% of check)					
3- to 4-leaf	98	87	89	92	87	93
Panicle initiation	97	90	91	88	52	48
Boot	68	46	46	90	91	88
LSD (0.05)	7					

[z] Glufosinate rate based on 0.55 lb/acre label rate, glyphosate rate based on 0.77 lb/acre label rate.

Table 5. Interaction of herbicide (glyphosate and glufosinate), rate (0.125×, 0.25×, and 0.5× labeled rate), and application timing in delaying heading compared to 89 days for the nontreated check, averaged across cultivars.[z]

	Delay in heading					
	Glufosinate			Glyphosate		
Application timing	0.125	0.25	0.5	0.125	0.25	0.5
3- to 4-leaf	0	2	8	2	5	17
Panicle initiation	2	9	17	3	10	17
Boot	25	48	48	39	48	48
LSD (0.05)	4					

[z] Glufosinate rate based on 0.55 lb/acre label rate, glyphosate rate based on 0.77 lb/acre label rate.

Table 6. Interaction of cultivar/hybrid, rate (0.125×, 0.25×, and 0.5× labeled rate) and application timing on rice seed weight as percent of nontreated check, averaged across herbicides.[z]

	Rice seed weight					
	Wells			XP723		
Application timing	0.125	0.25	0.5	0.125	0.25	0.5
	(% of check)					
3- to 4-leaf	98	98	97	99	98	95
Panicle initiation	97	93	89	99	94	95
Boot	94	89	95	95	88	86
LSD (0.05)	4					

[z] Glufosinate rate based on 0.55 lb/acre label rate, glyphosate rate based on 0.77 lb/acre label rate.

Table 7. Interaction of cultivar/hybrid, herbicide (glufosinate and glyphosate), and application timing on rice yield as percent of the nontreated check, averaged across rates.

	Rice yield			
	Wells		XP723	
Application timing	Glufosinate	Glyphosate	Glufosinate	Glyphosate
3- to 4-leaf	86	79	85	68
Panicle initiation	71	69	70	49
Boot	19	17	19	20
LSD (0.05)	8			

Environmental Implications of Pesticides in Rice Production

J.D. Mattice, B.W. Skulman, and R.J. Norman

ABSTRACT

For the past six years, we have collected and analyzed water in Arkansas from four sites each on the Cache, L'Anguille and St. Francis rivers from near Jonesboro in the north to near Marianna in the south and on Lagrue Bayou from just below Peckerwood Lake north of Stuttgart to near the mouth southeast of DeWitt. Since 2004, 52% to 93% of the detections over 2 ppb have been for quinclorac (Facet) and clomazone (Command). Each year, 60% to 90% of the detections that were over 2 ppb were less than 5 ppb, and 85% to 99% of the detections over 2 ppb were less than 10 ppb. The highest concentration in 2009 was 15.4 ppb for 2,4-D. The Cache and the L'Anguille rivers consistently have the most detections over 2 ppb. There is no trend for the overall frequency of detections over 2 ppb (5.4% in 2004, 3.7% in 2005, 3.3% in 2006, 6.3% in 2007, 5.2% in 2008, and 8.6% in 2009).

INTRODUCTION

The goal of this project is to determine if any environmental problems are developing in Arkansas surface waters as a result of pesticides used in rice production. Monitoring for pesticides in water may allow us to detect a potential problem and address it before it becomes a major problem. If no problems are being observed in the field, we will have documented what is present when no problems are seen.

Small rivers in watersheds that are predominately in rice-growing areas of the state would be the most sensitive barometers of potential problems due to pesticide use, since most of the water in the rivers would come from areas growing rice.

PROCEDURES

Sampling Sites

Four sites on each of four rivers have been established (Fig. 1). Water samples were collected on the L'Anguille River where it crosses highways US 79 near Marianna, US 64 near Wynne, State 14 near Harrisburg, and near Claypool reservoir north of Harrisburg. They were collected on the St. Francis River where it crosses US 79 near Marianna, US 64 near Parkin, State 75 near Marked Tree, and State 18 east of Jonesboro. Samples were collected on Lagrue Bayou at a county road approximately 0.5 km below Peckerwood Lake, the second bridge on highway 146 west of the highway 33 junction, near the town of Lagrue at highway 33 before the junction with highway 153, and where the Lagrue crosses highway 1 outside of DeWitt. Four samples were also collected on the Cache River where it crosses state highway 91 west of Jonesboro, a dirt road off county 37 at Algoa, state highway 260 near Patterson, and US 70 south of I-40.

Sampling Procedure

A 500-mL aliquot of each sample was extracted onto C18 disks in the field with a mobile extractor using conventional C18 disk technology. The disks were stored on ice packs and eluted on return to the lab. Samples were then analyzed by gas chromatography mass spectrometry (GCMS) and high-performance liquid chromatography (HPLC).

For quality control, at one site on each river four replicate subsamples were collected. Two subsamples were fortified with known amounts of the compounds and two were left unfortified. Analysis of these samples allowed us to verify recovery and reproducibility. Sampling was performed at 2-wk intervals during the rice production season from mid-April to mid-August.

The compounds chosen for analysis changed as their use in the field changed. Each year analysis is for approximately 9 to 13 compounds that we could reasonably expect to find. In 2009, analysis was for 8 pesticides and one pesticide degradation product. The compounds were, Command (clomazone), 2,4-D, Facet (quinclorac), Garlon (triclopyr), Pursuit (imazethapyr), Quadris (azoxystrobin), Raptor (imazamox), Stam (propanil), plus triclopyridinol (degradation product of triclopyr). Attempts were made to analyze for Ricestar (fenoxaprop) and Permit (halosulfuron); however recoveries of field fortified samples for both were unacceptably low and variable.

RESULTS AND DISCUSSION

Since the compounds require some water solubility to be active, and with the sensitive analytical equipment now available, it is not surprising to find low levels of pesticides in runoff water adjacent to fields when and where the compounds are used. Trying to find meaningful trends when looking at changes in small fractions of a part per billion (ppb) concentration in water would be difficult. There will be variability, but not necessarily meaningful variability in the sense of identifying a developing problem.

Since these are water samples from small rivers surrounded by rice fields, we have chosen a concentration of 2 ppb as the cutoff level for making comparisons.

Six of the samples collected on 16 April on the first sampling trip produced a total of six detections, four of which were for 2,4-D (Table 1). Finding this many detections of 2,4-D this early was unusual. Two of the 2,4-D detections were at the two most upstream sites on the L'Anguille and two were on the middle two sites on the St.Francis. The 15.4-ppb concentration found for 2,4-D at the most upstream site on the L'Anguille was also the highest detection found for any compound in 2009. The other two compounds found at this time were imazethapyr, which has been found this early before, and propanil. In 2008, three pesticides, one detection per pesticide, were made at this time. In 2007, only three different pesticides were detected on the first sampling trip, but there were a total of 12 detections on that trip.

In most years, clomazone and quinclorac were the two most frequently detected compounds. In 2009, quinclorac was the most frequently detected compound and azoxystrobin was second with clomazone being third (Table 1). A total of 74 samples provided 99 detections of compounds at concentrations greater than 2 ppb compared to 86 detections in 58 samples in 2008 and 102 detections from 73 samples in 2007. Quinclorac was detected in 42% of these 74 samples, azoxystrobin in 35%, and clomazone was detected in 19%. Eighty-four percent of the detections of quinclorac were after June 4, which is almost exactly the same as was found in 2008 when 82% were after June 4. In 2008, all but one of the 25 detections of clomazone (96%) occurred before July. In 2009, all but one of the 14 detections (93%) occurred before July. There were five instances, all in June, when both compounds were found in the same sample. Azoxystrobin was found from May through early August with no obvious, distinct grouping.

The 99 detections in 2009 are the second largest number of detections over the past 6 years and represent a decrease from the 102 detections in 2007 and an increase over the 86 detections over 2 ppb in 2008 (Table 2). Part of the reason for having more detections in 2009 is due to the increased detections of azoxystrobin, all but 2 of which were less than 5 ppb. In 2007 there were 16 detections and in 2008 there were 9. Overall this may reflect the extremes and variability that can be expected.

The distribution of concentrations in the 2 to 5 ppb concentration range has varied between 60% and 90% over the past 6 years (Table 3). Although the number of detections is the second highest we have found, the percentage of detections in the lowest concentration range is the highest and the percentages in the higher concentration ranges are the lowest, showing a shift toward lower concentrations compared to previous years.

The Cache and L'Anguille rivers flow parallel to each other and are similar in size. They both routinely produce the largest number of detections (Table 4). This was true again in 2009. Over the past 6 years, the Cache has averaged 30.8 detections per year and the L'Anguille has averaged 25.8 detections per year. For the last 6 years combined, these two rivers have accounted for 74% of the detections, although they have 50% of the sampling sites. The St. Francis and Lagrue Bayou have averaged 10.2 and 10.0 detections, respectively. The St. Francis is the largest of the four rivers, and Lagrue

Bayou is the smallest, yet they produce almost exactly the same number of detections. Part of the explanation may be that Lagrue Bayou comes out of Peckerwood Lake, which may serve as a reservoir where compounds can degrade before flowing into the bayou. The headwaters of the St.Francis are in southeastern Missouri where there is less rice agriculture than in Arkansas. Water flowing into Arkansas may initially dilute any compounds flowing into the river in northern Arkansas.

The number of detections at specific sites on the rivers lends support to the idea of a dilution effect on the lower portions of the L'Anguille and Cache rivers and the upper regions of the St. Francis and Lagrue Bayou (Table 4). The upper portions of the L'Anguille and Cache are completely surrounded by rice fields, so virtually all the water is coming from areas under rice agriculture. Farther downstream there could be a dilution effect if larger percentages of water flowing into these two rivers come from areas not under rice production. From 2004 to 2009 there were 122 detections from the uppermost sampling sites on the L'Anguille (site A) and the Cache (site Q) compared to only 57 at the lowest sites D and T consistent with a dilution effect. The reverse trend is observed for the St. Francis River and Lagrue Bayou. The uppermost sites on the St. Francis (E) and Lagrue (K) produced 13 detections over six years, and the two most downstream sites H (St.Francis) and N (Lagrue) produced 39 detections. Both situations demonstrate the value of having multiple sampling sites on rivers if they are being used to measure effects of runoff water into these rivers.

Each river has 25% of the sampling sites, but in four of the past six years most of the detections came from the Cache river (43% in 2004, 40% in 2005, 48% in 2008, and 34% in 2009; Table 4). In 2006, the L'Anguille and Cache rivers produced almost the same frequency of detections with 43% from the L'Anguille and 41% from the Cache, a difference of 1 detection. In 2007, the L'Anguille had 38 detections (37%) and the Cache had 34 detections (33%). In 2008, the L'Anguille had 28% of the detections and in 2009 it had 30%, almost proportional to the number of sampling sites (25%).

Over the past 6 years, 60% to 86% of the samples that contained a compound at a concentration > 2 ppb contained only one compound (Table 5). In 2009, 71% of the samples containing a compound contained only one. This is comparable to other years.

Detection of the same compound at the same site on consecutive sampling periods could indicate that the compound is being continually introduced into the river, as opposed to a limited, intermittent introduction. Quinclorac, which was detected most often, also was detected most frequently on consecutive sampling dates (Table 6). This occurred most frequently on the Cache River, which was also the river with the highest number of detections of quinclorac (Table 1). The L'Anguille and Lagrue had nine and eight detections of quinclorac respectively and had comparable consecutive detections at the same site (Table 6). Over the 6-year period, there is a period of time from late May through mid-June on the upper L'Anguille, especially site A, when we can expect to find both clomazone and quinclorac at concentrations over 2 ppb. On the Cache River, we can expect to find both compounds from the end of May through early July throughout most of the river, but especially the upper to middle part.

EPA does not have guidelines on acceptable levels for most of these compounds in either the National Recommended Water Quality Criteria - Correction (USEPA 1999) or the 2002 Edition of the Drinking Water Standards and Health Advisories (USEPA 2002). There was a listing of 70 ppb for the Maximum Contaminant Level (MCL) for 2,4-D in their drinking water standards. The highest level we found in river water was 25.5 ppb in 2007.

As mentioned previously (Mattice et al., 2007), comparing our results to EPA ecotoxicity data in the Pesticide Action Network database (PAN, 2007) indicates that on two occasions in the past 6 years concentrations of propanil (9.5 ppb in 2004) or 2,4-D (25.5 ppb in 2007) may have been high enough to cause an effect on some form of development of green algae or diatoms. These two compounds are rarely found, and when they are found they are usually at lower concentrations. None of the concentrations found in 2009 exceed these concentrations. These two compounds have been found infrequently in water because of their short environmental half-lives. The half-life of propanil is only 17 to 154 hr in environmental water (Anon, 2008a), and the half-life of 2,4-D in water ranges widely from 10 to >50 days, depending on environmental conditions. The half-life of 2,4-D in sediment and mud is less than 1 day (Anon, 2008b).

The two compounds that are most frequently found, clomazone and quinclorac, require higher concentrations to have a detrimental effect on a variety of test species. The highest concentration for clomazone in 2009 was over 100 times less than a concentration that did not have an observable effect (NOEL) on zooplankton, and the highest concentration of quinclorac was over 5000 times less than the LC50 for zooplankton. In 2009, azoxystrobin was also frequently found, but the highest concentration (5.5 ppb) was 10 times less than the LC50 required for acute toxicity to zooplankton and 122 times less than the LC50 for sheepshead minnow. Unless there is a strong synergistic effect among these compounds, they are not likely to be causing an environmental problem. We were not able to find any study in the literature investigating a possible synergism among these compounds.

SIGNIFICANCE OF FINDINGS

Most of the detections have been of low level and sporadic. Exceptions for being sporadic would be for quinclorac (Facet) in the middle part of the season (Tables 1 and 6). Quinclorac was detected frequently but usually at low concentrations. These results are generally similar to those of previous years. Comparing our results to ecotoxicity data indicates no developing environmental problem unless there is a strong synergism among clomazone, quinclorac, or azoxystrobin. Individually they have low toxicity, and there are no data available regarding a synergistic effect.

ACKNOWLEDGMENTS

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Table 1. Results for water samples that contain at least one detection of a pesticide for 2009.

			Compounds and concentrations detected[z]							
Date	River[y]	Site[x]	clom	imaz	quin	triol	2,4-D	tri	pro	azo
			-------------------- (ppb corrected for recovery)----------------------							
4/16	LA	A					15.4			
4/16	LA	B					2.0			
4/16	LA	C							2.4	
4/16	SF	F					5.6			
4/16	SF	G					3.1			
4/16	CA	T		8.4						
5/04	LA	A	5.0							
5/04	LA	B	3.1							
5/04	SF	G			3.2					
5/04	SF	H	2.6							
5/04	LG	N								3.3
5/05	CA	R	2.3							
5/18	LA	A				5.4				3.9
5/18	LA	B			2.6					
5/18	LA	C	2.4							
5/18	LA	D	3.0							5.3
5/18	SF	F								2.4
5/18	SF	G	2.3							
5/19	CA	S								4.8
6/04	LA	A					2.1			
6/04	LA	B	2.1							
6/04	LA	C	2.8		2.2					
6/04	SF	G					2.2			
6/04	LG	H	2.1		2.3					
6/04	LG	M			4.9					
6/05	CA	Q	3.9		3.7			6.6	7.6	
6/17	LA	A								3.1
6/17	LA	B			2.4					2.2
6/17	LA	D			2.8					
6/17	SF	F								3.8
6/17	SF	G					2.7			
6/17	SF	H			3.9					4.0
6/17	LG	K								4.6
6/17	LG	M			5.0					4.2
6/17	LG	N			4.0					
6/18	CA	Q	3.0		5.6					2.7
6/18	CA	R			4.1					
6/18	CA	S	2.0		2.7					
6/17	CA	T		3.5	2.1					2.6
7/01	LA	A			2.4	2.0				
7/01	LA	C			2.4				7.5	
7/01	LA	D			3.1					
7/01	LG	K					2.7			
7/01	LG	L			4.2					
7/01	LG	M			4.9					
7/01	LG	N			2.4		4.6			
7/02	CA	Q			5.0					

continued

Table 1. Continued.

			Compounds and concentrations detected[z]							
Date	River[y]	Site[x]	clom	imaz	quin	triol	2,4-D	tri	pro	azo
			-------------------- (ppb corrected for recovery)----------------------							
7/02	CA	R			3.3					
7/02	CA	S			3.8		2.6			
7/02	CA	T	2.1		3.3					
7/14	LA	C			2.8					
7/13	LA	D			2.1					
7/13	SF	G					2.2			3.2
7/13	SF	H				3.1				
7/13	LG	M			2.0					
7/13	LG	N			2.0					
7/14	CA	Q			2.1					
7/14	CA	R			3.9					
7/14	CA	S			2.9					
7/13	CA	T			2.4					
8/03	LA	A								2.0
8/03	LA	B								2.5
8/04	LA	C				5.0				
8/03	LA	D								2.1
8/03	SF	G								3.1
8/03	SF	G								3.2
8/03	SF	H								5.5
8/03	LG	K								3.5
8/03	LG	M						3.7		
8/03	LG	N								3.5
8/04	CA	Q			4.3					2.8
8/04	CA	R			2.8					4.3
8/04	CA	S			2.6					3.9
8/03	CA	T			2.0					2.5
Total			14	2	37	4	11	2	3	26
% in 74 samples			19	3	50	5	15	3	4	35
% in 99 detections			14	2	37	4	11	2	3	26

[z] clom = clomazone, imaz = imazethapyr, quin = quinclorac, triol = triclopyridinol, 2,4-D = 2,4-D, tri = triclopyr, pro = propanil, and azo = azoxystrobin.

[y] LA = L'Anguille, LG = Lagrue, CA = Cache, and SF = St Francis.

[x] A-D = L'Anguille upstream to downstream; D-H = St. Francis upstream to downstream; K-N = Lagrue upstream to downstream; and Q-T = Cache upstream to downstream.

Table 2. Frequency of detections over 2 ppb of pesticides in water by year for all four rivers.

Year	2004	2005	2006	2007	2008	2009
Possible detections	1440	1792	1792	1616	1664	1152
Detections	77	67	59	102	86	99
Percent	5.4	3.7	3.3	6.3	5.2	8.6

Table 3. Concentration distribution of pesticides in water by year.

Concentration range	Number of detections[z]					
	2004	2005	2006	2007	2008	2009
(ppb)						
2-5	63 (82%)	40 (60%)	48 (81%)	76 (75%)	57 (66%)	89 (90%)
5-10	13 (17%)	17 (25%)	7 (12%)	19 (19%)	19 (22%)	9 (9.1%)
10-40	1 (1%)	10 (15%)	4 (7%)	7 (7%)	10 (12%)	1 (1%)

[z] Percents may not total to 100 due to rounding to nearest percent.

Table 4. Detection frequency of pesticides in water over 2 ppb by river and site.

	Detection frequency					
River/Site	2004	2005	2006	2007	2008	2009
L'Anguille						
A[z]	9	4	10	14	13	9
B	5	2	4	10	6	7
C	9	4	10	9	3	8
D	2	2	1	5	2	6
Total	25	12	25	38	24	30
St. Francis						
E	0	0	2	1	0	0
F	3	0	1	3	1	3
G	3	2	0	6	4	9
H	3	1	2	6	4	7
Total	9	3	5	16	9	19
Lagrue						
K	2	0	0	2	3	3
L	3	1	1	5	3	1
M	1	2	2	3	6	6
N	4	0	2	4	0	6
Total	10	3	5	14	12	16
Cache						
Q	11	9	8	11	13	11
R	7	4	6	7	10	6
S	7	3	7	8	10	8
T	8	3	3	8	8	9
Total	33	19	24	34	41	34

[z] A-D = L'Anguille upstream to downstream; D-H = St. Francis upstream to downstream; K-N = Lagrue upstream to downstream; and Q-T = Cache upstream to downstream.

Table 5. Multiple detections of pesticides in river water over 2 ppb per sample.

No. of compounds per sample	Number of samples[z] 2004	2005	2006	2007	2008	2009
1	63 (82%)	34 (69%)	44 (86%)	46 (63%)	35 (60%)	53 (71%)
2	14 (18%)	12 (24%)	6 (12%)	25 (34%)	19 (33%)	18 (23%)
3	0	3 (6%)	1 (2%)	2 (3%)	3 (5%)	2 (3%)
4	0	0	0	0	1 (2%)	1 (1%)

[z] Percents may not total to 100 due to rounding to nearest percent.

Table 6. Consecutive detections of a given pesticide by site for 2009.

Date	clom[z]		quinclorac									24	az
5/18	C[y]												
6/4	C	Q			H	M		Q				G	
6/17		Q		D	H	M	N	Q	R	S	T	G	
7/1			C	D		M	N	Q	R	S	T		
7/14			C	D		M	N	Q	R	S	T		G
8/4								Q	R	S	T		G

[z] clom = clomazone, 24 = 2,4-D, and az = azoxystrobin.

[y] A-D = L'Anguille upstream to downstream; D-H = St. Francis upstream to downstream; K-N = Lagrue upstream to downstream; and Q-T = Cache upstream to downstream.

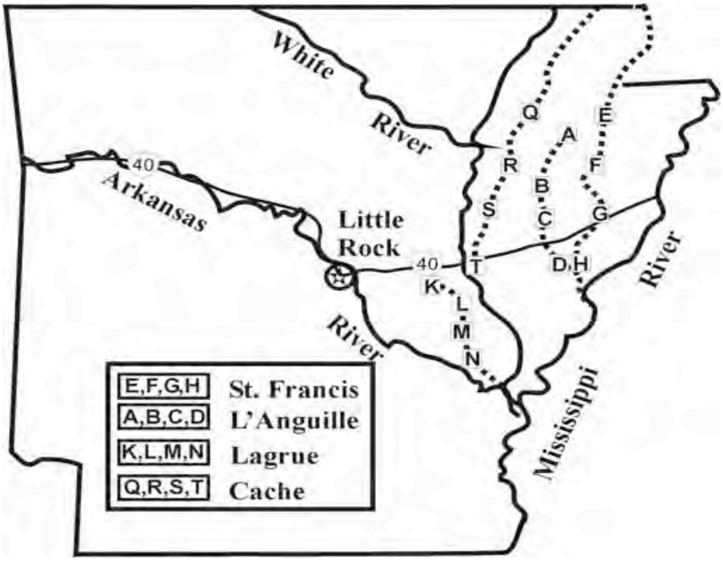

Fig. 1. Sampling sites for the 2009 water monitoring program.

PEST MANAGEMENT: WEEDS

Herbicide Combinations with Halosulfuron for Hemp Sesbania Control in Rice

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ABSTRACT

Halosulfuron (Permit 75DF) can be used for broadleaf and sedge control in a rice (*Oryza sativa*) production system. Halosulfuron is not intended to be used as a stand-alone herbicide in rice; therefore, there is a need to determine optimal herbicide combinations with halosulfuron to minimize antagonism and maximize weed control. Three field experiments were conducted at Stuttgart, Ark., to optimize herbicide combinations with halosulfuron for hemp sesbania (*Sesbania herbacea*) control in rice. Herbicides used in these experiments included: propanil (Stam), carfentrazone (Aim), and pyraflufen-ethyl (Vida) alone and in combination with halosulfuron. Plot layout was a four by five factorial design with different rates of each herbicide alone and in combination with halosulfuron. Propanil was applied at rates of 0, 1, 2, 3, and 4 lb ai/acre; carfentrazone at 0, 0.125, 0.25, and 0.5 oz ai/acre; and pyraflufen-ethyl at 0, 0.013, 0.026, and 0.052 oz ai/acre. In each experiment, halosulfuron was applied at rates of 0, 0.25, 0.5, 0.75, and 1 oz ai/acre. All treatments were applied to 12- to 15-inch hemp sesbania and rated for control 1, 4, and 8 weeks after treatment. The herbicide combination that resulted in the best season-long weed control was propanil plus halosulfuron. This combination provided the best season-long hemp sesbania control (>90%) across all rates and resulted in the least early-season rice injury (<7%). Pyraflufen-ethyl plus halosulfuron and carfentrazone plus halosulfuron both controlled hemp sesbania >90% at early-season ratings but declined to <90% later in the season unless applied at the highest rates. These combinations also caused the greatest early-season rice injury (up to 20%) of the herbicide combinations evaluated in these field experiments.

INTRODUCTION

Halosulfuron is labeled for use in rice and several other crops for the control of annual broadleaf weeds and sedges (Anonymous, 2007). Halosulfuron has good activity on broadleaf weeds but needs to be combined with other herbicides to provide a full spectrum of weed control. This creates a need to determine the best herbicide combinations with halosulfuron to maximize weed control. Halosulfuron alone controls <80% of hemp sesbania, but when halosulfuron was used in an acifluorfen program, hemp sesbania was controlled 100% (Talbert et al., 2000). The addition of halosulfuron and propanil to imazethapyr is needed to control hemp sesbania (Pellerin et al., 2003). Hemp sesbania is a major weed in rice production that can cause yield loss as high as 80% (Smith et al., 1988). This weed is a fast-growing, aggressive weed that can survive in flooded conditions and produces a large plant biomass. Hemp sesbania can hinder rice harvesting and can make harvesting almost impossible when left uncontrolled. Also, the small black seeds produced by this weed can reduce rice quality grade at the elevator, resulting in dockage. The control of hemp sesbania with herbicide combinations is important for efficiently producing a rice crop.

PROCEDURES

Three separate field experiments were conducted in a randomized complete block design with four replications at Stuttgart, Ark., in the summer of 2009. 'Wells' rice was drill-seeded at 24 seed/ft in plots 6 × 20 ft and was grown using conventional practices. The design was a four by five factorial layout, factor A being halosulfuron, and factor B being the tank-mix partner. Each herbicide was evaluated alone and in combination with halosulfuron (Permit) to determine the optimal ratio for maximum control and minimal antagonism. Each additive with halosulfuron was evaluated in separate experiments. Tank mix partners used in these experiments included: propanil (Riceshot), carfentrazone (Aim), and pyraflufen-ethyl (Vida). Propanil was applied at 0, 1, 2, 3, and 4 lb ai/acre; carfentrazone at 0, 0.125, 0.25, and 0.5 oz ai/acre; and pyraflufen-ethyl at 0, 0.013, 0.026, and 0.052 oz ai/acre. In each experiment, halosulfuron was applied at five rates: 0, 0.25, 0.5, 0.75, and 1 oz ai/acre. All treatments were applied to 12- to15-in. hemp sesbania and evaluated for control 1, 4, and 8 weeks after treatment (WAT). Rice injury ratings were taken 1 and 4 WAT.

RESULTS AND DISCUSSION

All herbicide combinations at most rates resulted in ≥90% hemp sesbania control at 1 WAT (Table 1). However, combinations of halosulfuron with pyraflufen-ethyl and carfentrazone resulted in slightly less control at 8 WAT, with several of the lower rates of the herbicide combinations resulting in <90% control. Halosulfuron plus propanil resulted in better late-season control of hemp sesbania, providing ≥90% control across several lower and higher rate combinations at 8 WAT. The herbicide combination that provided the best season-long control of hemp sesbania and the least amount of injury to rice was halosulfuron plus propanil.

Minimal rice injury was observed in association with halosulfuron (Table 2). Up to 20% of rice treated with pyraflufen-ethyl and carfentrazone was injured at 1 WAT, but rice plants fully recovered by 4 WAT. There was minimal injury associated with propanil (≤5%) application.

SIGNIFICANCE OF FINDINGS

Effectively controlling weeds in a crop production system can increase efficiency of production and use of resources. The findings of this research provide rice producers an effective herbicide combination for desirable season-long control of hemp sesbania. Additional research will be needed to determine the efficacy of the propanil plus halosulfuron combination on other common and troublesome weeds to rice.

ACKNOWLEDGMENTS

The financial support for this research was provided by the Arkansas Rice Research and Promotion Board, and the Gowan Company is thankfully acknowledged.

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Table 1. Hemp sesbania control 8 weeks after treatment.

	Hemp sesbania control											
Halosulfuron	Propanil				Carfentrazone				Pyraflufen-ethyl			
rate	0	2	3	4	0	0.125	0.25	0.5	0	0.013	0.026	0.052
(oz ai/acre)	--------------(lb ai/acre)--------------				-- (oz ai/acre) --							
0.00	0	80	79	92	0	10	0	31	0	11	55	51
0.25	23	78	73	89	42	81	90	88	38	68	77	93
0.50	73	85	88	96	77	91	81	90	31	77	83	87
0.75	78	84	95	95	79	87	89	92	58	87	91	90
1.00	83	84	97	93	82	93	90	90	68	91	90	97
LSD (0.05)	-------------------- 12 --------------------				-------------------- 21 --------------------				------------------- 19 ---------------------			

Table 2. Rice injury 8 weeks after treatment.

	Rice injury											
Halosulfuron	Propanil				Carfentrazone				Pyraflufen-ethyl			
rate	0	2	3	4	0	0.125	0.25	0.5	0	0.013	0.026	0.052
(oz ai/acre)	--------------(lb ai/acre)--------------				-- (oz ai/acre) --							
0.00	0	1	1	7	0	4	1	1	3	4	6	9
0.25	0	3	2	6	0	10	14	20	3	4	10	18
0.50	0	1	3	6	0	6	11	15	0	5	13	19
0.75	1	0	4	6	0	11	16	16	2	6	11	18
1.00	1	1	5	3	1	10	15	15	1	8	7	20
LSD (0.05)	--------------------- 3 --------------------				-------------------- 6 ---------------------				-------------------- 5 ---------------------			

PEST MANAGEMENT: WEEDS

Carfentrazone and Quinclorac Combinations at Various Rates and Timings for Broad Spectrum Weed Control in Rice

J.R. Meier, K.L. Smith, R.C. Scott, and J.K. Norsworthy

ABSTRACT

Trials were conducted in 2006 and 2009 at the Rohwer Research Station, near Rohwer, Ark., on a Sharkey clay soil to evaluate the efficacy of carfentrazone and quinclorac alone and in combination at various rates and application timing, and to compare tankmixes of carfentrazone and quinclorac with a new premix formulation. In 2006, the combination of quinclorac and carfentrazone applied at 1- to 2-leaf rice (EP) or at 3- to 4-leaf rice (MP) increased control of hemp sesbania [*Sesbania exaltata* (Raf.)] compared to carfentrazone alone 1 wk postflood. Control of hemp sesbania with quinclorac alone applied at both rates EP and MP was similar 1 wk preflood and at preflood; but by 1 wk postflood, control with quinclorac at 8 oz product/acre was greater from EP applications due to larger weed sizes at MP application. A similar trend was observed in 2009, whereas quinclorac, applied EP at 10.7 oz/acre, provided greater control of hemp sesbania and morningglory (*Ipomoea* spp.) compared to MP application, but application of carfentrazone at 1.9 oz/acre MP provided greater control than EP because it controlled weeds that emerged following EP application. Control of hemp sesbania and morningglory spp. with F-7275-2, applied EP, increased as rate increased from 4 oz to 8 oz/acre, but was similar between these rates when applied MP. Applying F-7275-2 at 8 and 12 oz/acre EP and MP provided similar control of hemp sesbania and morningglory spp. and was similar in control compared to carfentrazone and quinclorac in combination.

INTRODUCTION

Tank-mixing herbicides has become a common practice adopted by producers to lower application costs and to increase the spectrum of weed control from single applications. Tank-mixing herbicides with different modes of action can also improve control of some weed species, and more importantly, reduces the chances of herbicide resistance in weeds. Carfentrazone and quinclorac are commonly used herbicides alone and in tank-mixes for control of weeds in Arkansas rice production. Carfentrazone is a protoporphyrinogen oxidase (PPO) inhibitor labeled for broadleaf weed control in rice. Carfentrazone is a fast-acting herbicide notable for control of Indian (*Aeschynomene indica*) and northern jointvetch (*Aeschynomene virginica*), smartweed (*Polygonum* spp.), morningglories, and hemp sesbania (Mitchell and Sims, 1998; Mitchell and Gage, 1999a; Webster et al., 1999). Quinclorac is a synthetic auxin that became a replacement treatment option to control propanil-resistant barnyardgrass (*Echinochloa crus-galli*) (Baltazar and Smith, 1994; Talbert et al., 1995). Quincloac also provides control of other notable weeds such as broadleaf signalgrass (*Brachiaria platyphylla*), morningglory spp., jointvetch spp., and hemp sesbania, as well as residual control of these species (Morris et al., 1999; Scott et al., 2010; Street and Mueller, 1993). Due to restrictions in application, and the introduction of clomazone in 2000, quinclorac is not as widely used as before. Clomazone provides excellent control of grasses and some control of broadleaves when applied preemergence (Earnest et al., 1997; Jordan and Kendig, 1998; Mitchell and Gage, 1999b, Talbert et al., 1995; Webster et al., 1999), and it is estimated that 80% or more of the rice acreage in Arkansas is treated with clomazone (K.L. Smith, personal communication). Due to crop safety, higher rates are not recommended on lighter soils (Mitchell and Gage, 1999b; Scott et al., 2010) and consequently at lower use rates and/or poor water management, clomazone often dissipates to an ineffective level before permanent flood is established. When clomazone breaks before flood, a gap in control is created for grasses. Fenoxaprop and cyhalofop are labeled for grass control preflood or postflood but can be expensive, and tank-mixes with broadleaf herbicides are not recommended; therefore, another application for broadleaf weed control is needed. A combination of carfentrazone and quinclorac could potentially fill this gap in weed control. The objectives of this research were initially to determine the best timing for carfentrazone and quinclorac tank-mixes to be applied, and later to compare control of these tank-mixes with a premix formulation, F-7275-2.

PROCEDURES

Trials were conducted in 2006 and 2009 at the Rohwer Research Station near Rohwer, Ark., on a Sharkey clay soil. A randomized complete block design with four replications was used in both trials, and clomazone was applied to all plots preemergence at 0.3 lb ai/acre in 2006 and 0.25 lb ai/acre in 2009. This reduced rate was used with the intention to simulate a break in weed control prior to flood. Applications in both trials were made using a CO_2-pressurized backpack sprayer calibrated to deliver 12 gal/acre. In 2006, carfentrazone was applied at 1 and 1.5 oz/acre and quinclorac was applied at 8 and 10.7 oz/acre alone and in combinations at the 1- to 2-leaf (EP) and 3- to 4-leaf (MP) growth stages. In 2009, carfentrazone was applied at 1.9 oz/acre and quinclorac was applied at 10.7 oz/acre alone and in combination, and F-7275-2 was applied at 4, 8, and 12 oz/acre EP and MP. Control of hemp sesbania and barnyardgrass was evaluated in 2006 and 2009, and in 2009 morningglory spp. was also evaluated. Control was evaluated on a scale of 0 to 100% where 0 equals no control and 100 equals complete control. Data were subjected to ANOVA and means were separated using Fisher's Protected LSD Test (P = 0.05).

RESULTS AND DISCUSSION

In 2006, carfentrazone applied at both rates alone provided excellent control of hemp sesbania 7 and 14 days after application at all timings (data not shown). However, there are no residual effects from carfentrazone applications and emergence of new weeds after applications were made to rice EP and MP decreased the effectiveness of these treatments 1 wk preflood through 1 wk postflood (Table 1). Control of hemp sesbania with quinclorac alone applied at both rates EP and MP was similar at 1 wk preflood and preflood intervals, but by 1 wk postflood control with quinclorac at 8 oz/acre was greater from EP applications than from MP applications because of larger weed sizes at application. Increasing the rate of quinclorac from 8 to 10.7 oz/acre increased control of hemp sesbania 1 wk postflood and was equal between timings. Barnyardgrass control with quinclorac alone was generally greater from EP applications 1 wk preflood and preflood, but by 1 wk postflood, control of barnyardgrass with quinclorac at 8 and 10.7 oz/acre was greater from MP applications. The combination of quinclorac and carfentrazone, applied EP or MP, increased control of hemp sesbania compared to carfentrazone alone.

In 2009, a similar trend was observed in control of hemp sesbania and morningglory spp. with carfentrazone and quinclorac applied alone (Table 2). Applications of quinclorac at 10.7 oz/acre EP provided greater control of hemp sesbania and morningglory spp. compared to MP applications due to larger weed size. However, applications of carfentrazone at 1.9 oz/acre MP provided greater control than EP due to emergence of new weeds following EP applications at all evaluation intervals. When carfentrazone and quinclorac were combined, control of morningglory spp. and hemp sesbania was equal between EP and MP applications 1wk preflood through 1 wk postflood. The combination of carfentrazone and quinclorac, applied EP or MP, improved control of morningglory spp. and hemp sesbania compared to quinclorac alone MP. Control of hemp sesbania and morningglory spp. with F-7275-2, applied EP, increased as rate increased from 4 to 8 oz/acre, but was similar between these rates when applied MP. Applying F-7275-2 at 8 and 12 oz/acre EP and MP provided similar control of hemp sesbania and morningglory spp. over time, and was similar in control compared to carfentrazone and quinclorac in combination, applied EP and MP. There were no differences in barnyardgrass control in 2009 due to exceptional activity of clomazone applied preemergence, even at a reduced rate.

SIGNIFICANCE OF FINDINGS

Quinclorac alone provides control of hemp sesbania similar to carfentrazone but is not as fast-acting. Quinclorac also controls barnyardgrass and provides residual control which makes combinations with carfentrazone more desirable. This combination provides fast-acting broadleaf control of carfentrazone with the added grass and residual control of quinclorac that is beneficial in rice weed control programs following clomazone preemergence. The combination of carfentrazone and quinclorac also provides a greater window in application timing. Later applications at 3- to 4-leaf rice can be applied that will extend the residual control of quinclorac past permanent flood, and control of larger broadleaf weeds such has hemp sesbania can be achieved with carfentrazone. This combination continues to be a recommendation for weed control in Arkansas rice (Scott et al., 2010), and the premix product, F-7275-2, has been labeled as Broadhead™ from FMC Corporation and will be available to producers for use in 2010.

ACKNOWLEDGMENTS

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Table 1. Weed control following 1- to 2-leaf and 3- to 4-leaf rice application, Rohwer, 2006.

			Weed control					
	Growth		1 wk[z] preflood		Preflood		1 wk postflood	
Treatment	stage	Rate	SEBEX	ECHCG	SEBEX	ECHCG	SEBEX	ECHCG
		(rate/acre)	-----------------------	-----------------------	-----------------------	(%)	-----------------------	-----------------------
Carfentrazone	1-2 lf	1 oz	50	0	41	16	0	0
	3-4 lf		46	0	25	0	0	40
Carfentrazone	1-2 lf	1.5 oz	49	0	28	0	0	0
	3-4 lf		63	0	35	0	0	40
Quinclorac	1-2 lf	8 oz	78	78	48	60	80	60
	3-4 lf		73	73	55	45	70	80
Quinclorac	1-2 lf	10.7 oz	83	83	55	63	90	60
	3-4 lf		63	66	60	50	90	80
Carfentrazone + quinclorac	1-2 lf	1 oz + 8 oz	79	79	68	76	90	80
	3-4 lf		76	76	60	48	90	73
Carfentrazone + quinclorac	1-2 lf	1 oz + 10.7 oz	84	84	63	56	90	70
	3-4 lf		85	80	80	60	90	80
Carfentrazone + quinclorac	1-2 lf	1.5 oz + 8 oz	74	74	45	58	70	70
	3-4 lf		79	83	70	65	90	80
Carfentrazone + quinclorac	1-2 lf	1.5 oz + 10.7 oz	91	91	84	68	90	80
	3-4 lf		86	83	81	61	90	80
LSD (0.05)			15	11	21	16	1	1

[z] wk = week, SEBEX = hemp sesbania, ECHCG = barnyardgrass, and lf = leaf.

Table 2. Weed control following 1- to 2-leaf and 3- to 4-leaf applications, Rohwer, 2009.

			Weed control							
	Growth		1 wk[z] preflood			Preflood			1 wk postflood	
Treatment	stage	Rate	SEBEX	ECHCG	IPOSS	SEBEX	ECHCG	IPOSS	SEBEX	ECHCG
		(rate/acre)	(%)							
F-7275-2	1-2 lf	4 oz	60	100	64	70	100	70	50	100
	3-4 lf		84	100	95	81	100	84	68	100
F-7275-2	1-2 lf	8 oz	86	100	93	85	100	90	83	100
	3-4 lf		96	100	99	88	100	91	90	100
F-7275-2	1-2 lf	12 oz	95	100	93	93	100	89	88	100
	3-4 lf		100	100	100	99	100	100	100	100
Quinclorac	1-2 lf	10.7 oz	95	100	95	91	100	80	93	100
	3-4 lf		80	100	85	79	100	69	74	100
Carfentrazone	1-2 lf	1.9 oz	61	100	55	55	100	45	40	100
	3-4 lf		96	100	99	88	100	95	89	100
Quinclorac + carfentrazone	1-2 lf	10.7 oz + 1.9 oz	99	100	100	94	100	90	88	100
	3-4 lf		98	100	98	98	100	100	96	100
LSD (0.05)			11	NS	12	8	NS	17	10	NS

[z] wk = week, SEBEX = hemp sesbania, ECHCG = barnyardgrass, IPOSS = morningglory spp., lf = leaf, and NS = not significant.

Weed Control Programs with Imazosulfuron in Rice

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ABSTRACT

Imazosulfuron is a new sulfonylurea herbicide being developed by Valent for use in rice (*Oryza sativa*). It is known to have preemergence (PRE) and postemergence (POST) activity on various weeds in rice. However, imazosulfuron has little grass activity so it is not considered a stand-alone herbicide. It must be incorporated into herbicide programs that contain grass herbicides. Experiments were conducted at Keiser and Stuttgart, Ark., in 2009 to evaluate herbicide programs containing imazosulfuron with clomazone, quinclorac, propanil, and halosulfuron compared with a standard herbicide program in drill-seeded rice. At Keiser, imazosulfuron provided good control of hemp sesbania (*Sesbania herbacea*) PRE and excellent control POST, and control improved as the imazosulfuron rate increased. At Stuttgart, late-season hemp sesbania control was >99% across all programs. Preemergence imazosulfuron programs consistently provided better control of barnyardgrass (*Echinochloa crus-galli*) than POST programs. PRE and POST imazosulfuron programs helped control yellow nutsedge (*Cyperus escluentus*) but control was highly dependent on application rate. Programs containing the highest rate of imazosulfuron at 0.4 lb ai/acre provided season-long control of yellow nutsedge.

INTRODUCTION

The new sulfonylurea herbicide, imazosulfuron, being developed by Valent is a broadleaf herbicide intended for use in rice with an anticipated launch date of 2011. Imazosulfuron provides excellent control of several broadleaf weed species common in rice when applied PRE or POST (Jones et al., 2009). Postemergence applications include those made early postemergence (EPOST) at 2- to 3-wk after planting and preflood (PREFLD). Because weed control from imazosulfuron is limited to broadleaf weeds, it must be incorporated into rice herbicide programs that contain herbicides that have activity on grasses. Hemp sesbania, barnyardgrass, and yellow nutsedge are included in the top 10 most problematic weeds in rice in Arkansas (Norsworthy et al., 2007). Research is needed to determine where imazosulfuron fits into herbicide programs in rice for controlling these weeds. Our objective was to evaluate the effectiveness of imazosulfuron programs on control of six common rice weeds relative to a standard herbicide program in rice.

PROCEDURES

Field experiments were conducted at Keiser (clay soil) and Stuttgart (silt loam soil), Ark., in 2009. The design was a randomized complete block with four replications, and plots were 5 × 18 ft. 'Wells' rice was drill-seeded 19 May 2009, with various grass and broadleaf weed species being broadcast seeded the same day. Herbicide programs evaluated included imazosulfuron applied at 0.2, 0.3, and 0.4 lb ai/acre PRE with clomazone (Command) at 0.3 lb ai/acre followed by (fb) quinclorac (Facet) at 0.5 lb ai/acre plus propanil (Stam) at 4 lb ai/acre EPOST; imazosulfuron applied EPOST at 0.15, 0.2, and 0.3 lb/acre with clomazone at 0.3 lb/acre fb quinclorac 0.5 lb/acre plus propanil at 4 lb/acre PREFLD; imazosulfuron applied EPOST at 0.15, 0.2, and 0.3 lb/acre with quinclorac at 0.5 lb/acre fb thiobencarb at 3 lb/acre with propanil at 3 lb/acre applied PREFLD; imazosulfuron applied at 0.15, 0.2, and 0.3 lb/acre with clomazone at 0.3 lb/acre PRE fb quinclorac 0.5 lb/acre plus imazosulfuron at 0.15, 0.2, and 0.3 lb/acre PREFLD; and imazosulfuron applied PRE at 0.15, 0.2, and 0.3 lb/acre with clomazone 0.3 lb/acre fb imazosulfuron applied PREFLD at 0.15, 0.2, and 0.3 lb/acre with propanil at 4 lb/acre. The standard program for comparison consisted of clomazone 0.3 lb/acre plus quinclorac 0.5 lb/acre PRE fb propanil 4 lb/acre plus halosulfuron at 0.047 lb/acre PREFLD. All herbicides, excluding imazosulfuron, were applied at labeled rates. Clomazone use-rates were adjusted for soil type with 0.3 lb/acre applied on silt loam soil and 0.6 lb/acre applied on clay soil. All non-propanil POST treatments contained Dyne-A-Pak at 2.5% v/v, and a nontreated control was included. All applications were applied at 15 gal/acre. Weeds evaluated were hemp sesbania, barnyardgrass, yellow nutsedge, broadleaf signalgrass (*Brachiaria platyphylla*), pitted morningglory (*Ipomoea lacunosa*), and Palmer amaranth (*Amaranthus palmeri*). Visual ratings of rice injury and weed control were recorded at 8 and 12 weeks after planting (WAP) on a scale of 0 to 100 % with 100 % being complete weed control or rice injury. Rice yield data were recorded in bushels per acre (bu/acre). All data were subjected to analysis of variance, and means were separated using Fisher's protected Least Significant Difference (LSD) test at the 5% level of significance.

RESULTS AND DISCUSSION

Herbicide programs containing imazosulfuron caused little or no injury to rice (data not shown). At Keiser, PRE and POST activity on hemp sesbania from imazosulfuron herbicide programs ranged from 91% to 100% (Table 1). Programs that included PRE-applied imazosulfuron at 0.3 and 0.4 lb ai/acre, but no PREFLD herbicide resulted in >95% late-season (12 WAP) hemp sesbania control and was similar to programs that included PREFLD applications. Because of the clay soil at Keiser, it may be necessary to increase the imazosulfuron rate to 0.3 lb ai/acre when applied PRE in such treatments. The imazosulfuron rate of 0.3 lb ai/acre is the highest anticipated rate that will be labeled PRE in rice (Carey, personal communication). Control of barnyardgrass with all herbicide programs that included PRE- or EPOST-applied imazosulfuron fb quinclorac/propanil or thiobencarb/propanil POST was superior to other programs including the standard program (Table 1). Programs that included a POST application of a propanil/quinclorac or propanil/thiobencarb combination provided the highest pitted morningglory control at 8 WAP. Programs that included POST applications of quinclorac and propanil controlled Palmer amaranth at 8 WAP better than programs that contained POST applications of imazosulfuron. Imazosulfuron applied POST does not provide effective grass control (Jones et al., 2009) and must be used with grass herbicides. As a result, care must be given to controlling barnyardgrass in fields containing biotypes resistant to propanil and quinclorac.

On the Stuttgart silt loam soil, all treatments controlled hemp sesbania 99% to 100% and were comparable to the standard herbicide program (Table 2). Barnyardgrass and broadleaf signalgrass control was similar to the standard herbicide program when imazosulfuron was applied at rates greater than or equal to 0.2 lb ai/acre. Programs including EPOST fb PREFLD and PRE fb PREFLD applications provided >89% control of yellow nutsedge, which was comparable to control with the standard treatment. The soil types at the locations differed in clay content and subsequently affected the efficacy of imazosulfuron when applied PRE. Higher use rates of imazosulfuron than those evaluated here may be needed on clay soils. Because there was little or no injury to rice from imazosulfuron, yield from programs containing imazosulfuron were superior or equal to rice yield from the standard program (Table 3).

SIGNIFICANCE OF FINDINGS

The imazosulfuron-containing herbicide programs were highly efficacious on several weeds, but particularly on hemp sesbania and yellow nutsedge. Because of this, imazosulfuron appears to be an effective tool when coupled with grass herbicides for future weed management use in rice. In addition, adjustments in application rates depending on soil type may be necessary based on observations from these experiments.

ACKNOWLEDGMENTS

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Table 1. Late-season (12 WAP) hemp sesbania and barnyardgrass control at Keiser. Palmer amaranth and pitted morningglory control at 8 WAP at Keiser.

			Control			
Herbicide	Rate	Timing	Hemp sesbania	Barnyard-grass	Palmer amaranth	Pitted morningglory
	(lb ai/acre)		(%)			
Untreated check	None	None	0	0	0	0
Imazosulfuron	0.2	PRE^z	91	87	75	82
clomazone	0.6	PRE				
quinclorac	0.5	EPOST				
propanil	4	EPOST				
Imazosulfuron	0.3	PRE	99	89	99	95
clomazone	0.6	PRE				
quinclorac	0.5	EPOST				
propanil	4	EPOST				
Imazosulfuron	0.4	PRE	95	83	87	95
clomazone	0.6	PRE				
quinclorac	0.5	EPOST				
propanil	4	EPOST				
Imazosulfuron	0.15	EPOST	95	66	70	96
clomazone	0.6	EPOST				
quinclorac	0.5	PREFLD				
propanil	4	PREFLD				
Imazosulfuron	0.2	EPOST	100	79	67	96
clomazone	0.6	EPOST				
quinclorac	0.5	PREFLD				
propanil	4	PREFLD				
Imazosulfuron	0.3	EPOST	100	75	65	95
clomazone	0.6	EPOST				
quinclorac	0.5	PREFLD				
propanil	4	PREFLD				
Imazosulfuron	0.15	EPOST	100	87	60	100
quinclorac	0.5	EPOST				
thiobencarb	3	PREFLD				
propanil	3	PREFLD				
Imazosulfuron	0.2	EPOST	97	71	55	100
quinclorac	0.5	EPOST				
thiobencarb	3	PREFLD				
propanil	3	PREFLD				

continued

Table 1. Continued.

			Control			
Herbicide	Rate	Timing	Hemp sesbania	Barnyardgrass	Palmer amaranth	Pitted morningglory
	(lb ai/acre)		---------------------------- (%)	------------------------------		
Imazosulfuron	0.3	EPOST	100	89	65	99
quinclorac	0.5	EPOST				
thiobencarb	3	PREFLD				
propanil	3	PREFLD				
Imazosulfuron	0.15	PRE	100	65	36	67
clomazone	0.6	PRE				
quinclorac	0.5	PREFLD				
imazosulfuron	0.15	PREFLD				
Imazosulfuron	0.2	PRE	100	62	37	60
clomazone	0.6	PRE				
quinclorac	0.5	PREFLD				
imazosulfuron	0.2	PREFLD				
Imazosulfuron	0.3	PRE	100	59	27	84
clomazone	0.6	PRE				
quinclorac	0.5	PREFLD				
imazosulfuron	0.3	PREFLD				
Imazosulfuron	0.15	PRE	100	41	61	56
clomazone	0.6	PRE				
imazosulfuron	0.15	PREFLD				
propanil	4	PREFLD				
Imazosulfuron	0.2	PRE	100	64	65	72
clomazone	0.6	PRE				
imazosulfuron	0.2	PREFLD				
propanil	4	PREFLD				
Imazosulfuron	0.3	PRE	100	60	60	62
clomazone	0.6	PRE				
imazosulfuron	0.3	PREFLD				
propanil	4	PREFLD				
Clomazone	0.6	PRE	97	61	65	87
quinclorac	0.5	PRE				
halosulfuron	0.047	PREFLD				
propanil	4	PREFLD				
	LSD =		5.6	27	33.3	20.8

[z] PRE = preemergence, EPOST = early postemergence, and PREFLD = preflood.

Table 2. Late-season (12 WAP) hemp sesbania, barnyardgrass, broadleaf signalgrass, and yellow nutsedge control at Stuttgart.

			Control			
Herbicide	Rate	Timing	Hemp sesbania	Barnyard-grass	Broadleaf signalgrass	Yellow nutsedge
	(lb ai/acre)		---------------------------- (%)	------------------------------		
Untreated check	None	None	0	0	0	0
Imazosulfuron	0.2	PRE[z]	99	100	100	60
clomazone	0.3	PRE				
quinclorac	0.5	EPOST				
propanil	4	EPOST				
Imazosulfuron	0.3	PRE	100	100	100	81
clomazone	0.3	PRE				
quinclorac	0.5	EPOST				
propanil	4	EPOST				
Imazosulfuron	0.4	PRE	100	99	100	89
clomazone	0.3	PRE				
quinclorac	0.5	EPOST				
propanil	4	EPOST				
Imazosulfuron	0.15	EPOST	100	85	93	100
clomazone	0.3	EPOST				
quinclorac	0.5	PREFLD				
propanil	4	PREFLD				
Imazosulfuron	0.2	EPOST	100	85	91	100
clomazone	0.3	EPOST				
quinclorac	0.5	PREFLD				
propanil	4	PREFLD				
Imazosulfuron	0.3	EPOST	100	86	91	99
clomazone	0.3	EPOST				
quinclorac	0.5	PREFLD				
propanil	4	PREFLD				
Imazosulfuron	0.15	EPOST	100	95	98	98
quinclorac	0.5	EPOST				
thiobencarb	3	PREFLD				
propanil	3	PREFLD				
Imazosulfuron	0.2	EPOST	100	96	98	100
quinclorac	0.5	EPOST				
thiobencarb	3	PREFLD				
propanil	3	PREFLD				
Imazosulfuron	0.3	EPOST	100	97	99	99
quinclorac	0.5	EPOST				
thiobencarb	3	PREFLD				
propanil	3	PREFLD				
Imazosulfuron	0.15	PRE	100	97	92	89
clomazone	0.3	PRE				
quinclorac	0.5	PREFLD				
imazosulfuron	0.15	PREFLD				
Imazosulfuron	0.2	PRE	100	100	99	94
clomazone	0.3	PRE				
quinclorac	0.5	PREFLD				
imazosulfuron	0.2	PREFLD				

continued

Table 2. Continued.

Herbicide	Rate	Timing	Control Hemp sesbania	 Barnyard-grass	 Broadleaf signalgrass	 Yellow nutsedge
	(lb ai/acre)		----------------------------	(%)	------------------------------	
Imazosulfuron	0.3	PRE	100	99	95	99
clomazone	0.3	PRE				
quinclorac	0.5	PREFLD				
imazosulfuron	0.3	PREFLD				
Imazosulfuron	0.15	PRE	99	91	92	97
clomazone	0.3	PRE				
imazosulfuron	0.15	PREFLD				
propanil	4	PREFLD				
Imazosulfuron	0.2	PRE	99	92	96	94
clomazone	0.3	PRE				
imazosulfuron	0.2	PREFLD				
propanil	4	PREFLD				
Imazosulfuron	0.3	PRE	99	98	94	99
clomazone	0.3	PRE				
imazosulfuron	0.3	PREFLD				
propanil	4	PREFLD				
Clomazone	0.3	PRE	100	100	100	100
quinclorac	0.5	PRE				
halosulfuron	0.047	PREFLD				
propanil	4	PREFLD				
		LSD =	0.5	7.7	7.3	10.8

[z] PRE = preemergence, EPOST = early postemergence, and PREFLD = preflood.

Table 3. Rice yields at Keiser and Stuttgart, Ark., as influenced by herbicide programs.

			Yield	
Herbicide	Rate	Timing	Stuttgart	Keiser
	(lb ai/acre)		------------- (bu/acre)	------------
Untreated check	None	None	0	26
Imazosulfuron	0.2	PRE[z]	200	163
clomazone	0.3	PRE		
quinclorac	0.5	EPOST		
propanil	4	EPOST		
Imazosulfuron	0.3	PRE	202	175
clomazone	0.3	PRE		
quinclorac	0.5	EPOST		
propanil	4	EPOST		
Imazosulfuron	0.4	PRE	189	176
clomazone	0.3	PRE		
quinclorac	0.5	EPOST		
propanil	4	EPOST		
Imazosulfuron	0.15	EPOST	191	129
clomazone	0.3	EPOST		
quinclorac	0.5	PREFLD		
propanil	4	PREFLD		
Imazosulfuron	0.2	EPOST	191	146
clomazone	0.3	EPOST		
quinclorac	0.5	PREFLD		
propanil	4	PREFLD		
Imazosulfuron	0.3	EPOST	188	145
clomazone	0.3	EPOST		
quinclorac	0.5	PREFLD		
propanil	4	PREFLD		
Imazosulfuron	0.15	EPOST	181	190
quinclorac	0.5	EPOST		
thiobencarb	3	PREFLD		
propanil	3	PREFLD		
Imazosulfuron	0.2	EPOST	185	165
quinclorac	0.5	EPOST		
thiobencarb	3	PREFLD		
propanil	3	PREFLD		
Imazosulfuron	0.3	EPOST	186	176
quinclorac	0.5	EPOST		
thiobencarb	3	PREFLD		
propanil	3	PREFLD		
Imazosulfuron	0.15	PRE	187	147
clomazone	0.3	PRE		
quinclorac	0.5	PREFLD		
imazosulfuron	0.15	PREFLD		
Imazosulfuron	0.2	PRE	192	167
clomazone	0.3	PRE		
quinclorac	0.5	PREFLD		
imazosulfuron	0.2	PREFLD		
Imazosulfuron	0.3	PRE	189	122
clomazone	0.3	PRE		
quinclorac	0.5	PREFLD		
imazosulfuron	0.3	PREFLD		

continued

Table 3. Continued.

Herbicide	Rate	Timing	Yield Stuttgart	 Keiser
	(lb ai/acre)		------------- (bu/acre)	------------
Imazosulfuron	0.15	PRE	178	137
clomazone	0.3	PRE		
imazosulfuron	0.15	PREFLD		
propanil	4	PREFLD		
Imazosulfuron	0.2	PRE	176	113
clomazone	0.3	PRE		
imazosulfuron	0.2	PREFLD		
propanil	4	PREFLD		
Imazosulfuron	0.3	PRE	176	166
clomazone	0.3	PRE		
imazosulfuron	0.3	PREFLD		
propanil	4	PREFLD		
Clomazone	0.3	PRE	161	153
quinclorac	0.5	PRE		
halosulfuron	0.047	PREFLD		
propanil	4	PREFLD		
		LSD =	26.7	48.6

[z] PRE = preemergence, EPOST = early postemergence, and PREFLD = preflood.

PEST MANAGEMENT: WEEDS

Herbicide Programs for Controlling ALS-Resistant Barnyardgrass in Arkansas Rice

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ABSTRACT

Barnyardgrass is the most problematic weed in Arkansas rice production, causing yield reduction, lodging, and poor grain quality. It infests most of the Arkansas rice acreage, with biotypes resistant to propanil (Stam), quinclorac (Facet), and clomazone (Command). Clearfield (imidazolinone-tolerant) rice has led to extensive use of the imazethapyr herbicide in rice. Along with the use of other acetolactate synthase (ALS)-inhibiting herbicides such as penoxsulam and bispyribac, the evolution of resistant barnyardgrass was inevitable. In early 2009, an ALS-resistant barnyardgrass biotype was documented through the annual screening program at the University of Arkansas. Thus, an effective herbicide program is needed for control of the ALS-resistant biotype. A field study was conducted in the summer of 2009 at Lonoke, Ark., on a silt loam soil to determine herbicide programs that would provide effective control of the susceptible and resistant biotypes. Imazethapyr (Newpath) at 0.063 lb ai/acre was applied alone and in combination with clomazone at 0.3 lb ai/acre, quinclorace at 0.5 lb ai/acre, pendimethalin at 1 lb ai/acre, thiobencarb at 4 lb ai/acre, and fenoxaprop at 0.11 lb ai/acre at multiple timings [preemergence (PRE), delayed preemergence (DPRE), early postemergence (EPOST), and preflood (PREFLD)]. Two applications of imazethapyr alone were ineffective in controlling the resistant biotype but did control the susceptible biotype. Programs that contained clomazone, quinclorac, pendimethalin, and thiobencarb PRE or DPRE followed by split applications of imazethapyr EPOST and PREFLD alone or tank-mixed with fenoxaprop controlled at least 90% of both biotypes. Therefore, alternative herbicide programs were effective in controlling the ALS-resistant barnyardgrass biotype.

INTRODUCTION

Arkansas produces close to half of the rice in the United States making it important to U.S. crop production (Wilson and Branson, 2005). Arkansas rice production increased 5% from 2008 to 2009 (NASS, 2009). Since the commercialization of Clearfield rice in 2002, the acreage on which this technology has been used has increased each year, with 45% to 50% of the acreage planted in Clearfield cultivars/hybrids in 2009 (Wilson, personal communication). Clearfield rice allows for the use of multiple applications of imazethapyr, an ALS-inhibiting herbicide, for the control of problematic grass weeds such as barnyardgrass (*Echinochloa crus-galli*), red rice (*Oryza sativa*), and suppression of some broadleaf weeds (Norsworthy et al., 2007). Additionally, imazamox (Beyond) is often applied postflood for control of red rice escapes. There are currently barnyardgrass biotypes in Arkansas that are known to be resistant to propanil, quinclorac, and clomazone (Baltazar and Smith, 1994; Carey et al., 1994; Lovelace et al., 2002; Norsworthy et al., 2008). With the repetitive use of imazethapyr (Newpath) as well as penoxsulam (Grasp) and bispyribac (Regiment), other commonly used ALS herbicides, the evolution of ALS-resistant barnyardgrass in rice is inevitable. In early 2009, an ALS-resistant barnyardgrass was confirmed from a rice field in northeast Arkansas. Due to the single site of ALS-resistance and the possibility for increased occurrence because of the continued, repeated use of this technology, there is a definite need for controlling the resistant biotype in Clearfield rice systems. We hypothesized that ALS herbicides will fail to control the ALS-resistant biotype, but alternative herbicide programs will effectively control the ALS-resistant and other barnyardgrass biotypes.

PROCEDURES

Field experiments were conducted in a randomized complete block design replicated four times at Lonoke, Ark., in 2009. Clearfield 151 rice was seeded with a 9-row drill on 7-in. spacings. Barnyardgrass, both susceptible and ALS-resistant biotypes, was planted in rows perpendicular to the rice rows, which were 6 ft × 20 ft. Imazethapyr (Newpath) at 0.063 lb ai/acre applied EPOST followed by PREFLD was evaluated alone or in combination with clomazone (Command 3ME) at 0.3 lb ai/acre, quinclorace (Facet) at 0.5 lb ai/acre, pendimethalin (Prowl H20) at 1 lb ai/acre, thiobencarb (Bolero) at 4 lb ai/acre, or fenoxaprop (Ricestar HT) at 0.11 lb ai/acre. Herbicide applications were made at timings of PRE, DPRE, EPOST, and PREFLD. All postemergence applications contained 0.25% v/v nonionic surfactant (NIS) and were applied at 15 gal/acre. A nontreated control was also included. Weekly visual ratings were taken throughout the growing season to evaluate barnyardgrass control, and crop yields were obtained at harvest. Data were subjected to analysis of variance, and means were separated by Fisher's protected least significant difference test at the 5% level of significance.

RESULTS AND DISCUSSION

Two applications of imazethapyr applied alone successfully controlled the susceptible biotype (Table 1), also reported by Wells and Bond (2006). However, imazethapyr failed to control the resistant biotype at 4, 6, and 10 weeks after planting (WAP) (30% to 44%). When two applications of imazethapyr were applied in combination with clomazone, quinclorac, pendimethalin, thiobencarb, or fenoxaprop effective control of both resistant and susceptible biotypes was obtained throughout the season (88% to 100%). There was no injury to the rice crop and yields did not differ (data not shown) simply because one row of barnyardgrass would not compete severely with the crop. We found that the ALS-herbicide imazethapyr did not provide effective control of the ALS-resistant biotype; although when applied with other herbicides, the resistant biotype was effectively controlled. Therefore, our hypothesis was correct.

SIGNIFICANCE OF FINDINGS

Alternative herbicide programs were found to control the ALS-resistant barnyardgrass biotype making this problematic weed less competitive to a rice crop. Future research will consist of quantifying the level of resistance of the ALS-resistant biotype, testing for cross and multiple resistance, and determining its ecological fitness compared to susceptible barnyardgrass biotypes. Although additional ALS herbicides were not evaluated in these trials, it is unlikely that they will provide control of the resistant biotype in the field based on observed failure under greenhouse conditions.

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Table 1. Barnyardgrass control 4, 6, and 10 wk after planting (WAP).

Herbicide application	Rate	Timing	Barnyardgrass control 4 WAP susc.^{z}	4 WAP res.	6 WAP susc.	6 WAP res.	10 WAP susc.	10 WAP res.
	(lb ai/acre)		(%)					
Untreated check	None	EPOST	0	0	0	0	0	0
Imazethapyr	0.063	EPOST	91	43	82	30	100	44
imazethapyr	0.063	PREFLD						
Clomazone	0.3	PRE	98	98	91	91	100	88
imazethapyr	0.063	EPOST						
imazethapyr	0.063	PREFLD						
Clomazone	0.3	PRE	96	95	100	100	100	98
quinclorac	0.5	PRE						
imazethapyr	0.063	EPOST						
imazethapyr	0.063	PREFLD						
Pendimethalin	1.0	DPRE	98	98	99	100	100	95
quinclorac	0.5	DPRE						
imazethapyr	0.063	EPOST						
imazethapyr	0.063	PREFLD						
Pendimethalin	1.0	DPRE	98	98	100	100	100	100
thiobencarb	4.0	DPRE						
imazethapyr	0.063	EPOST						
imazethapyr	0.063	PREFLD						
Quinclorac	0.5	DPRE	99	96	100	100	100	99
thiobencarb	4.0	DPRE						
imazethapyr	0.063	EPOST						
imazethapyr	0.063	PREFLD						

continued

Table 1. Continued.

Herbicide application	Rate	Timing	Barnyardgrass control 4 WAP susc.[z]	4 WAP res.	6 WAP susc.	6 WAP res.	10 WAP susc.	10 WAP res.
	(lb ai/acre)		(%)					
Clomazone	0.3	DPRE	98	98	100	99	100	95
pendimethalin	1.0	DPRE						
imazethapyr	0.063	EPOST						
imazethapyr	0.063	PREFLD						
Imazethapyr	0.063	EPOST	95	43	91	43	100	93
imazethapyr	0.063	PREFLD						
fenoxaprop	0.11	PREFLD						
Clomazone	0.3	PRE	100	99	99	100	100	100
imazethapyr	0.063	EPOST						
imazethapyr	0.063	PREFLD						
fenoxaprop	0.11	PREFLD						
Clomazone	0.3	PRE	100	98	100	100	100	100
quinclorac	0.5	PRE						
imazethapyr	0.063	EPOST						
imazethapyr	0.063	PREFLD						
fenoxaprop	0.11	PREFLD						
Pendimethalin	1.0	DPRE	93	90	100	100	100	97
quinclorac	0.5	DPRE						
imazethapyr	0.063	EPOST						
imazethapyr	0.063	PREFLD						
fenoxaprop	0.11	PREFLD						
Pendimethalin	1.0	DPRE	100	100	100	100	100	100
thiobencarb	4.0	DPRE						
imazethapyr	0.063	EPOST						
imazethapyr	0.063	PREFLD						
fenoxaprop	0.11	PREFLD						
Quinclorac	0.5	DPRE	100	98	95	89	100	94
thiobencarb	4.0	DPRE						
imazethapyr	0.063	EPOST						
imazethapyr	0.063	PREFLD						
fenoxaprop	0.063	PREFLD						
Clomazone	0.3	DPRE	88	90	95	94	100	88
pendimethalin	1.0	DPRE						
imazethapyr	0.063	EPOST						
imazethapyr	0.063	PREFLD						
fenoxaprop	0.11	PREFLD						
		LSD =	3	12	8	14	0	17

[z] PRE = preemergence, DPRE = delayed preemergence, EPOST = early postemergence, PREFLD = preflood, and susc. = susceptible.

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

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ABSTRACT

The DD50 computer program has been one of the most successful programs developed by the University of Arkansas Division of Agriculture. The program utilizes thermal units accumulated during the growing season to calculate predicted dates the rice will reach critical growth stages. However, the Degree-Day 50 (DD50) 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 in the dry-seeded, delayed-flood management system most commonly used in the southern United States. Conventional rice cultivars evaluated in 2009 were as follows: 'Bowman', 'Catahoula', 'CL111', 'CL131', 'CL142AR', 'CL151', 'C171AR', 'CL181AR', 'JazzMan', 'JES', 'Neptune', 'Roy J', 'Taggart', 'Templeton', 'Wells', and one experimental line RU0701124. Commercial hybrid cultivars included: 'ArizeQM1003', 'CL XL729', 'CL XL745', and 'XL723'. Grain yields are measured at maturity to evaluate the influence of seeding date on yield potential.

INTRODUCTION

The DD50 computer program was developed in 1978 by the University of Arkansas, Division of Agriculture for use as a management tool and approximately 40% of Arkansas rice farmers use this program each year. The program utilizes cultivar-specific data to predict plant development based on the accumulation of DD50 thermal units from the date of seedling emergence. These data are acquired from annual studies of promising experimental lines and all newly released conventional and hybrid rice cultivars. Each new cultivar remains in the study for a minimum of three years. When a new cultivar is released, the data from these studies are used to provide threshold DD50 thermal units in the DD50 computer program to enable predictions of dates when plant development stages will occur and dates when specific management practices should be performed. Therefore, the objectives of this study are 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 2009 at the University of Arkansas Rice Research and Extension Center (RREC) near Stuttgart, Ark., on a DeWitt silt loam soil. Sixteen conventional rice cultivars (Bowman, Cathoula, CL111, CL131, CL142AR, CL181AR, JazzMan, JES, Neptune, RU0701124, Roy J, Taggart, Templeton, and Wells) were drill-seeded at a rate of 40 seed/ft^2 in nine-row (7-in. spacing) wide plots, 17 ft in length. The Bayer Crop Science hybrid (ArizeQM1003) and the three RiceTec hybrids (XL723, CL XL729, and CL XL745), were each sown into the same plot configuration using hybrid seeding rates of 14 seed/ft^2. General seeding, seedling emergence, and flood dates are shown in Table 1. The seeding dates were 30 March, 16 April, 19 May, and 16 June 2009. Normal cultural practices for dry-seeded delayed flood rice were followed. All plots received 120 lb N/acre as a single preflood application of urea at the 4- to 5-leaf growth stage. The permanent flood was applied and maintained until the rice reached maturity. Data collected included: maximum and minimum daily temperatures, seedling emergence, and the number of days and DD50 thermal units required to reach 0.5-in. internode elongation (IE) and 50% heading. At maturity, the center four rows of each plot was harvested, the moisture content and weight of the grain were determined, and a subsample of harvested grain removed for milling purposes. Grain yields were adjusted to 12% moisture and reported on a bu/acre basis. The dried rice was milled to obtain percent total white rice and percent head rice. Each seeding date was arranged as a randomized complete block with three replications. Statistical analyses were conducted with SAS and mean separations were conducted based upon Fisher's protected LSD ($\alpha = 0.05$) where appropriate.

RESULTS AND DISCUSSION

The time between seeding and emergence ranged from 6 to 21 days (Table 1). Generally in seeding date studies, the time between seeding and emergence decreases as seeding date is delayed. This was also observed during 2009. Also, as the seeding date was delayed, the time between seeding and flooding was generally shorter, ranging from 51 days for the 30 March seeding date, increasing slightly to 55 days for the 16 April seeding date and decreasing to 34 and 23 days for the 19 May and 16 June seeding dates, respectively. During 2009, the time from emergence to flooding ranged from 17 to 40 days for each of the four seeding dates. The longest period between emergence and flooding was observed for the 16 April planting date, and might be attributed to the cool temperatures during parts of late April and May.

The time required from emergence to 0.5-in. IE averaged 53 days across all cultivars and seeding dates (Table 2). During 2009, time of vegetative growth averaged across planting dates ranged from 45 days for the long-grain experimental line RU0701124 to 60 days for the medium-grain cultivar Neptune. Average time for all cultivars to reach 0.5-in. IE ranged from 61 days when seeded in late March to 41 days when seeded in June. The number of days required by each cultivar to reach 0.5-inch IE were similar between the March and April planning dates, and then decreased with each subsequent seeding date. The DD50 thermal unit accumulations during vegetative growth ranged from a low of 1250 for CL111 to a high of 1579 for Neptune when averaged across seeding dates. Thermal unit accumulations were highest for each cultivar in the 16 April seeding as compared to the other three seeding dates.

The time required for development between emergence and 50% heading averaged 84 days across all cultivars and seeding dates during 2009 (Table 3). Average time for all cultivars to reach 50% heading ranged from 94 days when seeded 16 April to 75 days when seeded 16 June. The number of days required by each cultivar to reach 50% heading generally declines as seeding date is delayed, but was greatest in the April seeding date during 2009. The number of days for Wells to reach 50% heading was 85 when averaged across seeding dates, and most cultivars were within three days of Wells during 2009. However, RU0701124 and RiceTec CLXL745 were notably earlier, averaging 12 and 5 days earlier than Wells, respectively. The cultivars ArizeQM1003, Roy J, Taggart, and Templeton were 4 to 6 days later than Wells during 2009. Across seeding dates, average DD50 thermal unit accumulation ranged from a low of 1924 for RU071124 to a high of 2414 for Roy J.

Five cultivars produced grain yields of 180 bu/acre or greater when averaged across seeding dates during 2009 (Table 4). These included Wells, and the hybrids ArizeQM1003, CL XL729, CL XL745, and XL723. During this study year, all cultivars maximized grain yield when seeded either 30 March or 16 April. It should be noted that ArizeQM1003, JES, CLXL729, XL723, Roy J, and Wells also performed well when seeded on 19 May.

Milling yield of many of the cultivars was fairly consistent among the first three seeding dates, but declined when seeded 16 June (Table 5). Two of the higher yielding cultivars, Wells and XL723, also maintained desirable milling yields when averaged across seeding dates.

SIGNIFICANCE OF FINDINGS

The data from 2009 will be used to refine the DD50 thermal unit thresholds for the new cultivars and hybrids being grown. The grain and milling yield data will be used to help producers make decisions regarding rice cultivar selection, particularly for early and late seeding situations.

ACKNOWLEDGMENTS

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Table 1. General seeding, seedling emergence, and flooding date information for the DD50 seeding date study in 2009 at the Rice Research and Extension Center near Stuttgart, Ark.

	Seeding date			
Parameter	30 March	16 April	19 May	16 June
Emergence date	20 April	1 May	28 May	22 June
Flood date	20 May	10 June	22 June	9 July
Days from seeding to emergence	21	15	8	6
Days from seeding to flooding	51	55	34	23
Days from emergence to flooding	30	40	26	17

Table 2. Influence of seeding date on DD50 accumulations and days from emergence to 0.5-in. internode elongation of selected rice cultivars in studies conducted at the Rice Research and Extension Center during 2009.[z]

	0.5-in. internode elongation									
	30 March		16 April		19 May		16 June		Average	
Cultivar	Days	DD50 units	Days	DD50 units	Days	DD50 units	Days	DD50 units	Days	DD50 units
ArizeQM1003	60	1362	58	1398	44	1288	37	1078	50	1281
Bowman	66	1532	68	1720	54	1564	45	1290	58	1527
Catahoula	59	1308	57	1366	45	1309	37	1080	49	1266
CL111	58	1277	57	1377	44	1267	37	1080	49	1250
CL131	.	.	.	.	.	.	.	.	.	.
CL142AR	61	1372	61	1511	48	1398	44	1264	53	1386
CL151	57	1266	56	1334	44	1288	40	1157	49	1261
CL171AR	.	.	.	.	.	.	.	.	.	.
CL181AR	61	1383	59	1450	49	1428	42	1224	53	1371
JazzMan	67	1564	65	1635	52	1506	47	1349	58	1514
JES	63	1447	62	1541	48	1397	40	1159	53	1386
Neptune	67	1575	68	1700	55	1578	50	1463	60	1579
RTCLXL729	.	.	.	.	.	.	.	.	.	.
RTCLXL745	57	1266	57	1377	47	1357	41	1178	50	1294
RTXL723	60	1351	57	1377	46	1339	40	1167	51	1308
RU0701124	55	1195	55	1302	40	1153	32	937	45	1147
Roy J	65	1500	66	1643	51	1482	44	1264	56	1472
Taggart	64	1479	64	1582	50	1458	43	1245	55	1441
Templeton	62	1426	63	1561	50	1448	43	1244	55	1420
Wells	61	1394	63	1572	50	1448	44	1272	55	1421
Mean	61	1394	61	1497	48	1394	41	1203	53	1372
C.V.	1.9	2.6	1.5	2.0	1.9	1.9	2.4	3.0	--	--
LSD	1.9	60.4	1.6	48.6	1.5	43.4	1.6	46.0	--	--

[z] The cultivars CL131, CL171AR, and RTCLXL729 were not used in these determinations.

Table 3. Influence of seeding date on DD50 accumulations and days from emergence to 50% heading of selected rice cultivars in studies conducted at the Rice Research and Extension Center during 2009.

	50% Heading									
	30 March		16 April		19 May		16 June		Average	
Cultivar	Days	DD50 units	Days	DD50 units	Days	DD50 units	Days	DD50 units	Days	DD50 units
ArizeQM1003	96	2422	101	2639	82	2354	78	2191	89	2402
Bowman	91	2297	96	2489	80	2278	75	2097	86	2290
Catahoula	89	2247	97	2527	76	2173	68	1931	83	2219
CL111	87	2175	90	2330	79	2261	72	2043	82	2202
CL131	83	2077	90	2322	78	2238	72	2028	81	2166
CL142AR	88	2211	92	2384	80	2278	76	2125	84	2249
CL151	83	2066	89	2306	80	2269	76	2124	82	2191
CL171AR	89	2231	98	2548	81	2319	76	2125	86	2306
CL181AR	88	2197	95	2460	81	2300	75	2097	85	2264
JazzMan	89	2247	94	2430	80	2299	76	2135	85	2278
JES	93	2334	98	2538	81	2320	78	2175	87	2342
Neptune	93	2328	93	2410	80	2289	78	2174	86	2300
RTCLXL729	84	2106	89	2287	83	2371	76	2116	83	2220
RTCLXL745	82	2045	85	2192	78	2219	71	2013	79	2117
RTXL723	87	2191	90	2313	82	2340	74	2067	83	2228
RU0701124	78	1911	80	2058	70	1984	61	1741	72	1924
Roy J	96	2403	102	2680	82	2351	79	2223	90	2414
Taggart	93	2329	99	2576	82	2340	77	2165	88	2352
Templeton	92	2315	99	2576	83	2366	78	2173	88	2357
Wells	89	2248	96	2497	80	2290	76	2116	85	2287
Mean	89	2219	94	2428	80	2282	75	2093	84	2255
C.V.	1.7	1.8	1.3	1.4	4.5	4.7	6.3	5.7	--	--
LSD	2.5	67.5	2.0	57.1	5.9	176.6	7.7	196.7	--	--

Table 4. Influence of seeding date on grain yield of selected rice cultivars in studies conducted at the Rice Research and Extension Center during 2009.

	Grain yields				
Cultivar	30 March	16 April	19 May	16 June	Average
	(bu/acre)				
ArizeQM1003	222	228	193	138	196
Bowman	209	174	145	75	151
Catahoula	176	165	148	97	146
CL111	204	185	147	111	162
CL131	175	181	160	144	165
CL142AR	184	176	149	103	153
CL151	231	192	167	124	178
CL171AR	182	161	154	117	153
CL181AR	198	195	152	126	167
JazzMan	202	185	127	98	153
JES	209	177	188	115	172
Neptune	210	216	175	109	178
RTCLXL729	273	246	183	146	212
RTCLXL745	240	216	162	121	185
RTXL723	263	212	201	149	206
RU0701124	171	182	127	121	150
Roy J	179	184	183	97	161
Taggart	230	195	165	95	171
Templeton	232	191	167	119	177
Wells	215	192	191	135	183
Mean	210	193	164	117	171
C.V.	8.9	7.6	14.5	23.0	--
LSD	30.9	24.2	39.4	NS	--

Table 5. Influence of seeding date on milling yield of selected rice cultivars in studies conducted at the Rice Research and Extension Center during 2009.

	Milling yields				
Cultivar	30 March	16 April	19 May	16 June	Average
	-------------------------------(% HR-% TR[z]) --				
ArizeQM1003	57-65	63-67	45-37	50-68	54-66
Bowman	58-68	65-68	40-66	27-53	47-64
Catahoula	66-73	68-72	53-63	60-67	62-69
CL111	61-69	66-70	55-67	53-66	59-68
CL131	66-72	68-71	59-69	59-67	63-70
CL142AR	63-72	65-71	54-69	49-63	58-69
CL151	58-69	64-68	57-67	49-61	57-66
CL171AR	65-71	68-71	57-69	53-65	61-69
CL181AR	59-67	64-70	63-68	55-63	60-67
JazzMan	64-71	66-68	61-70	52-64	61-68
JES	61-69	66-69	57-68	53-67	59-68
Neptune	70-72	71-73	66-71	62-69	67-71
RTCLXL729	61-70	65-71	61-69	55-66	60-69
RTCLXL745	58-70	66-73	53-70	50-64	56-69
RTXL723	61-70	67-71	65-71	47-69	60-70
RU0701124	61-67	63-67	53-63	45-60	55-65
Roy J	59-69	63-68	60-68	56-65	60-68
Taggart	60-71	65-71	60-67	41-60	56-67
Templeton	62-70	67-70	57-67	39-64	57-68
Wells	64-72	66-70	61-69	54-65	61-69
Mean	62-70	66-70	57-68	50-64	59-68

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

Grain Yield Response of Fourteen 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 cultivars across the array of soil and climatic conditions that exist in the Arkansas rice-growing region. The fourteen rice cultivars studied in 2009 were: ‘Bowman’, ‘Catahoula’, ‘Neptune’, ‘Taggert’, ‘Templeton’, ‘Jazzman’, ‘JES’, Horizon AG’s Clearfield ‘CL111’, ‘CL142AR’, ‘CL151’, and ‘CL181AR’, Bayer Crop Science’s ‘ArizeQM1003’; and the Arkansas experimental varieties ‘RU0701124’ and ‘RU0801076’. ArizeQM1003 should maximize yields when 90 to 120 lb N/acre is applied to silt loam soils in a 50 to 90 lb N/acre preflood application followed by 30 lb N/acre at the late boot stage. The varieties Bowman, CL151, JES, and RU0701124 should maximize yield on most silt loam soils when 120 lb N/acre is applied in a two-way split application of 75 lb N/acre at preflood followed by 45 lb N/acre at midseason. When these five varieties are grown on clay soils, the preflood N rate should increase by 30 lb N/acre and the midseason N rate or the boot N rate should stay the same at 45 lb N/acre or 30 lb N/acre, respectively. The varieties Catahoula, Taggart, and Templeton should maximize yield on most silt loam soils when 150 lb N/acre is applied in a two-way split application of 105 lb N/acre at preflood followed by 45 lb N/acre at midseason. When these aforementioned varieties are grown on clay soils, the preflood N rate should increase to 135 lb N/acre and the midseason N rate should stay the same. The variety Neptune fell between the previous two N rate groups and should maximize yield on most silt loam soils when 135 lb N/acre is applied in a two-way split application of 90 lb N/acre at preflood followed by 45 lb N/acre at midseason. When Neptune is grown on clay soils, the preflood N rate should increase by 30 lb N/acre and the midseason N

rate should stay the same. The other varieties tested need at least another year of study before any recommendations on N rate can be made.

INTRODUCTION

The Variety × Nitrogen (N) Fertilizer Rate Study measures the grain yield performance of the new rice cultivars over a range of N fertilizer rates on representative clay and silt loam soils and determines the proper N fertilizer rates to maximize yield on these soils under the climatic conditions that exist in Arkansas. Promising new rice selections from breeding programs in Arkansas, Louisiana, Mississippi, and Texas as well as those from private industry are evaluated in this study. Fourteen cultivars were studied in 2009 at one to three locations, depending on seed supply. Louisiana had the two new semi-dwarf varieties in the study, a medium- and long-grain, named Neptune and Catahoula, respectively. Mississippi has a new semi-dwarf, long-grain named Bowman. Horizon AG entered four Clearfield, long-grain varieties named CL111 and CL151 in cooperation with Louisiana and CL142AR and CL181AR in cooperation with Arkansas. Clearfield rice varieties are tolerant to the broad-spectrum herbicide imazethapyr (Newpath). Bayer CropScience entered a long-grain, hybrid rice variety named ArizeQM1003. There were two experimental lines in the study from Arkansas in 2009 entered as RU0701124 and RU0801076.

PROCEDURES

Locations where the Variety × N Fertilizer Rate Study were conducted and corresponding soil series are as follows: Lake Hogue Research Farm (LHRF), in Poinsett County near Weiner, Ark., on a Hillemann silt loam (Thermic, Albic, Glossic Natraqualfs); Northeast Research and Extension Center (NEREC), Keiser, Ark., on a Sharkey clay (Vertic Haplaquepts); and the Rice Research and Extension Center (RREC), near Stuttgart, Ark., on a DeWitt silt loam (Typic Albaqualfs). The experimental design utilized was a randomized complete block with four replications at all locations for all the rice cultivars studied. A single preflood N fertilizer application was utilized for all cultivars, except the hybrid ArizeQM1003 from Bayer CropScience. The preflood N fertilizer was applied as urea onto a dry soil surface at 4- to 5-leaf stage. The preflood N rates were: 0, 60, 90, 120, 150, 180, and 210 lb N/acre. The Bayer hybrid ArizeQM1003 had the N fertilizer applied in a two-way split application scheme at preflood and late-boot (BT) in the following total N (preflood N + BT N) rate splits: 0 (0+0), 60 (30+30), 90 (60+30), 120 (90+30), 150 (120+30), 180 (150+30), and 210 (180+30) lb N/acre. The studies on the two silt loam soils at the LHRF 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 lb N/acre more N fertilizer to maximize grain yield when grown on clay soils compared to the silt loams. The rice was drill-seeded in plots nine-rows wide (row spacing of 7 in.), 15 ft. in length at a rate of 100 lb/acre on the silt loam soils and 130 lb/acre on the clay soil, except the Bayer CropScience hybrid. The Bayer hybrid ArizeQM1003 was seeded at 45 lb/acre on the clay and silt loam soils. Rice was seeded on 16 April at the RREC, on 20 May at the NEREC, and on 21 May at the LHRF (Table 1). The studies were flooded at each location when the rice was at the 4- to 5-leaf stage and within 2 days of preflood N fertilization. The studies remained flooded until the rice was mature. At maturity, the plots were trimmed to 12 ft in length and then all rows of each plot were harvested, the moisture content and weight of the grain were determined, and yields were calculated as bu/acre at 12% moisture. A bushel (bu) of rice weighs 45 pounds (lb). Statistical analyses were conducted with SAS and mean separations were based upon protected LSD ($p = 0.05$) 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 semi-dwarf 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. The rice varieties typically require 20 to 30 lb N/acre less when the N is applied in a single preflood application compared to two-split applications where the second split is applied between beginning internode elongation (IE) and 0.5-inch IE. 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 preflood N application.

Pertinent agronomic information such as planting dates and flood dates are shown in Table 1. A wet spring delayed planting at the LHRF and the NEREC and then a cool wet fall delayed harvest and led to some lodging and grain quality problems. The yields and lodging were affected the most adversely at the NEREC, the northernmost location.

Bowman did not significantly increase in grain yield when more than 60 lb N/acre was applied preflood on the silt loam soil at the LHRF, 90 lb N/acre on the silt loam soil at the RREC, and 120 lb N/acre on the clay soil at the NEREC (Table 2). Rice grown on clay soils usually requires 30 to 60 lb/acre more N fertilizer to maximize yield compared to when grown on silt loam soils. The silt loam soil at the LHRF has only been in row crop production for about 10 years and thus, contains a higher level of native soil N compared to the same soil that has been in production for several decades. The variability of native soil N among silt loam soils is why a soil test for N is needed to accurately recommend an N rate for individual fields. Bowman a had maximum grain yield of about 175 bu/acre on the silt loam soils at the LHRF and the RREC and 168 bu/acre on the clay soil at the NEREC. The grain yield of Bowman displayed a significant decrease at the LHRF when the N rate required to reach the peak grain yield was exceeded. This yield decrease by Bowman was not evident at the RREC nor at the NEREC, except at the 210 lb N/acre rate. The high native-soil fertility at the

LHRF certainly contributed to this yield decrease at the high N rates. The three years of N-rate data gathered on Bowman suggest Bowman will probably require around 120 lb N/acre in a two-way split application of 75 lb N/acre preflood followed by 45 lb N/acre at midseason to maximize grain yield when grown on most silt loam soils (Norman et al., 2008, 2009). Bowman will require about 150 lb N/acre in a two-way split application (105 lb N/acre preflood, 45 lb N/acre midseason) when grown on clay soils to obtain maximum yield.

Catahoula did not significantly increase in grain yield when more than 60 lb N/acre was applied preflood on the silt loam soil at the LHRF and when more than 90 lb N/acre was applied preflood on the silt loam soil at the RREC and the clay soil at NEREC (Table 3). Catahoula obtained peak grain yields of around 170 bu/acre when grown on the silt loam soils at the LHRF and the RREC, but only reached a maximum yield of 128 bu/acre when grown on the clay soil at the NEREC. Catahoula had similar low yields at the NEREC in 2008 (Norman et al., 2009). The combination of the NEREC being the northernmost location coupled with the late plantings in 2008 and 2009 probably indicate that Catahoula does not yield well when planted late. Catahoula appeared to have a stable grain yield when 30 to 60 lb N/acre more than what was required to maximize yield were applied. Results from 2008 and 2009 indicate that Catahoula will probably require 150 lb N/acre in a two-way split application of 105 lb N/acre preflood followed by 45 lb N/acre at midseason when grown on silt loam soils to maximize yield (Norman et al., 2009). When grown on clay soils, the preflood N rate for silt loam soils should be increased by 30 lb N/acre and the midseason N rate should remain at 45 lb N/acre.

Neptune was able to achieve a maximum grain yield of 214 bu/acre on the silt loam soil at the RREC when 150 lb N/acre was applied preflood, but did not significantly increase in yield at the RREC when more than 120 lb N/acre was applied preflood (Table 4). Neptune achieved a maximum yield of 193 bu/acre on the silt loam soil at the LHRF when 90 lb N/acre was applied preflood, but did not significantly increase in yield at the LHRF when more than 60 lb N/acre was applied. Neptune reached the 200 bu/acre level on the clay soil at the NEREC when 150 lb N/acre was applied preflood. The grain yield of Neptune did not significantly increase on the clay soil at the NEREC when more than 120 lb N/acre was applied preflood. Neptune did not display the lodging problems in 2009 that were observed in 2008 (Norman et al., 2009) even though we were not able to harvest as timely as we wanted to in the fall of 2009 due to rainy weather. The first two years of data on Neptune indicate that it will probably require on most silt loam soils 135 lb N/acre applied in a two-way split application of 90 lb N/acre preflood followed by 45 lb N/acre at midseason to maximize yield (Norman et al., 2009). When grown on clay soils, the preflood N rate for silt loam soils should be increased by 30 lb N/acre and the midseason N rate should remain at 45 lb N/acre to maximize yield.

Taggart reached a maximum grain yield of 181 bu/acre on the silt loam soil at the LHRF when 90 lb N/acre was applied preflood and went over the 200 bu/acre level with 210 bu/acre on the silt loam soil at the RREC when 150 lb N/acre was applied preflood

(Table 5). Taggart only obtained a grain yield of 158 bu/acre at the NEREC and this was achieved when only 90 lb N/acre was applied preflood to the clay soil at this location. The combination of the NEREC being the northernmost location and the late planting probably contributed to the low yield and it being obtained with such a low N rate. The grain yields Taggart obtained at the LHRF and the RREC indicate that it has very good yield potential when not planted too late. Taggart did not appear to be able to maintain its yield when N rates greater than that required to maximize yield were applied at the LHRF. However, Taggart was able to maintain its yield when high N rates were applied at the NEREC and the RREC and the results from 2007 (Norman et al., 2008) and 2008 (Norman et al., 2009) indicate that Taggart typically has a stable yield without lodging when N rates greater than that required to maximize yield were applied. The data over the last three years (Norman et al., 2008, 2009) indicate that Taggart should maximize grain yield on most silt loam soils when 150 lb N/acre is applied in a two-way split application of 105 lb N/acre preflood and 45 lb N/acre at midseason. To maximize yield when grown on most clay soils, the preflood N rate should be 135 lb N/acre followed by a second application of 45 lb N/acre at midseason.

Templeton produced top yields of 233 and 187 bu/acre on the silt loam soils at the RREC and the LHRF, respectively (Table 6). Grain yields of Templeton did not significantly increase when more than 60 lb N/acre was applied preflood at the LHRF and 120 lb N/acre at RREC. Templeton, similar to Taggart, only produced a top yield of 157 bu/acre on the clay soil at the NEREC and this was basically achieved when only 120 lb N/acre was applied preflood. Rice grown on clay soils typically require at least 150 lb N/acre and typically 180 lb N/acre to maximize yield. The combination of the NEREC being the northernmost location and the late planting probably contributed to the low yield and it being obtained with such a low N rate. Templeton in 2009 and in years passed (Norman et al., 2008, 2009) showed a stable yield without lodging when N rates greater than that required to maximize yield were applied. Templeton should maximize grain yield on most silt loam soils 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. To maximize yield when grown on most clay soils, the preflood N rate should be 135 lb N/acre followed by a second application of 45 lb N/acre at midseason.

Jazzman produced over 200 bu/acre at the RREC where it was seeded 16 April, but only obtained grain yields around 150 bu/acre at the LHRF and NEREC where it was seeded around 20 May (Tables 1 and 7). Consequently, Jazzman may not yield well when it is seeded in late May or June. Jazzman did not significantly increase in grain yield when more than 90 lb N/acre was applied preflood to the silt loam soil at the LHRF and was able to maintain this yield when up to 180 lb N/acre was applied preflood. Grain yield did not significantly increase above 150 bu/acre on the clay soil at the NEREC when more than 90 lb N/acre was applied preflood. Late planted rice that does not yield well may also not need as much N to maximize yield as when it is planted earlier and obtains a higher yield more representative of its yield potential. At the RREC, where Jazzman did yield well (i.e., 204 bu/acre), an N rate of 150 lb N/acre at preflood was required to reach that yield. Jazzman did not significantly increase in yield on the silt loam soil at the RREC when up to 180 lb N/acre was applied preflood.

Jazzman appeared to have a stable yield without any lodging when N rates greater than that required to maximize yield were applied. This is the first year Jazzman was in the Variety × N Study so no firm recommendations can be made at this time.

JES achieved grain yields over 200 bu/acre on the silt loam soils at the LHRF and RREC when only 60 and 90 lb N/acre was applied preflood, respectively (Table 8). JES did not yield well on the clay soil at NEREC due to the late planting at this northernmost location and because of lodging. JES obtained a maximum yield of only 125 bu/acre at the NEREC with 55% lodging when only 90 lb N/acre was applied preflood. Lodging increased and yields decreased as the N rate was increased to 210 lb N/acre. JES does not require as much N fertilizer as most rice varieties to achieve maximum yields over 200 bu/acre. However, JES is more prone to lodging compared to most other varieties when more N fertilizer is applied than what is required to maximize yield. Interestingly, JES did not lodge at all at the RREC even when N rates greater than that required to maximize yield were applied. The results from 2008 (Norman et al., 2009) and 2009 indicate that JES should require an N rate of 120 lb N/acre applied in a two-way split application of 75 lb N/acre at preflood and 45 lb N/acre at midseason to maximize grain yield on most silt loam soils. Two years of results on JES when grown on the clay soil at the NEREC indicate that the N rate recommended for silt loam soils should be utilized on clay soils.

CL151 achieved a maximum yield of 200 bu/acre with no measurable lodging at the LHRF when 60 lb N/acre was applied preflood (Table 9). When 90 lb N/acre was applied preflood, minimal lodging of CL151 was measured and a grain yield of 189 bu/acre was obtained. Lodging became much worse when the N rate was increased to 120 lb N/acre at the LHRF and steadily increased, while grain yield decreased as the N rate was raised to 180 lb N/acre. The lodging led to a high LSD at this location. CL151 essentially peaked in grain yield at around 170 bu/acre when 120 lb N/acre was applied preflood to the clay soil at the NEREC. Yields were down for all varieties tested at the NEREC in 2009 due to it being the northernmost location and the late planting from a wet spring. Measurable lodging of CL151 was observed when 120 lb N/acre was applied and the lodging increased and grain yield decreased as N rate increased. As observed at the LHRF, the lodging of CL151 at the NEREC led to a high LSD at this location. CL151 had a maximum grain yield of 183 bu/acre on the silt loam soil at the RREC when 90 lb N/acre was applied preflood. The native soil N was not as high on the silt loam soil at the RREC compared to the LHRF. CL151 maintained a steady grain yield when 90 to 150 lb N/acre was applied preflood at the RREC and then significantly decreased when the N rate increased to 180 lb N/acre. CL151 experienced no lodging at the RREC in 2009. CL151 has exceptional yield potential and can achieve maximum yield on most silt loam soils when 90 lb N/acre or less is applied in a single preflood application and on a clay soil when 120 lb N/acre is applied in a single preflood application. After two years of study (Norman et al., 2009), CL151 should maximize grain yield on most silt loam soils when 120 lb N/acre is applied in a two-way split application of 75 lb N/acre at preflood and 45 lb N/acre at midseason. When CL151 is grown on clay soil, 150 lb N/acre should be applied in a two-way split application of 105 lb N/acre at preflood and 45 lb N/acre at midseason.

Three new Clearfield rice varieties, CL111, CL141AR, and CL181AR, were placed in the Variety × N Fertilizer Rate Study in 2009, but due to lack of seed they could only be tested at the RREC (Table 10). CL141AR had the highest yield of the three Clearfield varieties at 189 bu/acre when 150 lb N/acre was applied preflood, but did not significantly increase in grain yield when more than 120 lb N/acre was applied. CL111 obtained a maximum yield of 181 bu/acre when 150 lb N/acre was applied preflood and reacted similarly to CL141 with no significant increase in grain yield when more than 120 lb N/acre was applied preflood. CL181AR had the lowest yield of the three with 174 bu/acre when 120 lb N/acre was applied preflood, but did not significantly increase in grain yield when more than 90 lb N/acre was applied preflood. All three varieties showed good yield stability and no lodging when N rates greater than that to achieve maximum yield were applied.

ArizeQM1003 reached a maximum grain yield of 267 bu/acre at the LHRF when only 60 lb N/acre was applied at preflood (Table 11). Amazingly, ArizeQM1003 achieved yields well over 200 bu/acre at all of the preflood N rates applied from 30 to 150 lb N/acre. ArizeQM1003 displayed minimal lodging at the LHRF through the highest N rate. The late planting and harvest along with NEREC being the northernmost location caused grain yields to be the lowest of the three locations. ArizeQM1003 produced a peak grain yield at the NEREC of only 167 bu/acre when 90 lb N/acre was applied preflood. Due to lodging and possibly the higher N rates delaying maturity too long during the cool fall, the grain yield of ArizeQM1003 decreased erratically as N rate increased. Lodging was as unusual at NEREC as it was at the LHRF, but in a different way. Lodging at the NEREC began and peaked when 120 lb N/acre was applied preflood and occurred at all of the N rates through 210 lb N/acre, in a somewhat decreasing fashion. ArizeQM1003 produced grain yields over 200 bu/acre when 60 to 150 lb N/acre were applied preflood at the RREC. Grain yield of ArizeQM1003 at the RREC peaked at 240 bu/acre when 120 lb N/acre was applied preflood. Lodging of ArizeQM1003 was not a problem at the RREC in 2009 as it was in 2008. The ArizeQM1003 hybrid tested in 2009 yielded much better than the one tested in 2008 with much less lodging. After two years of study, the results indicate the ArizeQM1003 hybrid will probably yield the best with minimal lodging when grown on most silt loam soils if 60 to 90 lb N/acre is applied preflood followed by 30 lb N/acre at late boot. When ArizeQM1003 is grown on clay soil, a good N fertilizer regime would be 90 to 120 lb N/acre applied preflood followed by 30 lb N/acre at late boot.

The Arkansas experimental variety RU0701124 achieved 200 bu/acre at the LHRF when only 60 lb N/acre was applied preflood (Table 12). Lodging was a problem for RU0701124 at the LHRF due to a late planting and delayed harvest. The yield of RU0701124 declined quickly and lodging increased substantially at the LHRF when the N rate was increased from 60 to 180 lb N/acre. The yield of RU0701124 was affected the most from the late planting and delayed harvest at the NEREC. RU0701124 obtained a yield of 172 bu/acre when 150 lb N/acre was applied preflood to the clay soil at the NEREC. The yield of RU0701124 declined and the lodging increased as the N rate increased from 150 to 210 lb N/acre at the NEREC. RU0701124 did not experience any lodging at the RREC where we were able to plant in April. RU0701124 essentially reached maximum yield when 90 lb N/acre was applied preflood at the RREC and was able to maintain this yield with no lodging as the N rate was increased to 180 lb N/acre. This may indicate that RU0701124 should be planted early and harvested timely to minimize the risk of lodging. After two years of study, the results indicate that RU0701124 when grown on most silt loam soils will maximize yield and minimize lodging if 75 lb N/acre is applied preflood followed by 45 lb N/acre at midseason. When RU0701124 is grown on clay soil, a good N fertilizer regime would be 105 lb N/acre applied preflood followed by 45 lb N/acre at midseason.

A preliminary N fertilizer rate study was conducted on the silt loam soil at the RREC with the Arkansas experimental rice variety RU0801076 (Table 13). RU0801076 achieved a maximum yield of 196 bu/acre when 150 lb N/acre was applied preflood, but did not significantly increase in yield above the 188 bu/acre obtained when 90 lb N/acre was applied preflood. RU0801076 displayed a stable yield when 90 to 180 lb N/acre was applied and displayed no evidence of lodging. Overall, RU0801076 appears to have a good yield potential and some resistance to lodging. Further research needs to be conducted in 2010 at all three locations before we can fully evaluate the N rate required to maximize the yield of RU0801076.

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 yield when grown commercially in the Arkansas rice-growing region. Fourteen rice cultivars were studied in 2009: Bowman; Catahoula; Neptune; Taggart; Templeton; Jazzman; JES; Horizon AG's Clearfield CL111, CL142AR, CL151, and CL181AR; Bayer CropScience's ArizeQM1003; and the Arkansas experimental varieties RU0701124, and RU0801076. 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 silt loam and clay soils in Arkansas.

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Table 1. Pertinent agronomic information for the Lake Hogue Research Farm (LHRF), Northeast Research and Extension Center (NEREC), and the Rice Research and Extension Center (RREC) during 2009.

Practices	LHRF	NEREC	RREC
Planting dates	5/21	5/20	4/16
Emergence dates	5/29	6/01	5/01
Preflood N dates	6/23	7/09	6/09
Flood dates	6/24	7/10	6/10
50% Heading dates	mid August	late August - early September	late July - early August
Harvest dates	mid October	early - mid November	early - mid September

Table 2. Influence of nitrogen (N) fertilizer rate on the grain yield of Bowman rice at three locations during 2009.

N Fertilizer	Grain yield		
rate	LHRF[z]	NEREC	RREC
(lb N/acre)	------------------------------	(bu/acre[y])	-------------------------------
0	120	84	100
60	175	--	153
90	164	155	171
120	149	162	176
150	139	167	172
180	133	160	172
210	---	149	---
$LSD_{(0.05)}$	11	11 9	

[z] LHRF = Lake Hogue Research Farm, Wiener, Ark.; NEREC = Northeast Research and Extension Center, Keiser, Ark.; and RREC = Rice Research and Extension Center, Stuttgart, Ark.

[y] A bushel of rice weighs 45 lb.

Table 3. Influence of nitrogen (N) fertilizer rate on the grain yield of Catahoula rice at three locations during 2009.

N Fertilizer	Grain yield		
rate	LHRF[z]	NEREC	RREC
(lb N/acre)	------------------------------ (bu/acre[y])	------------------------------	
0	134	86	93
60	174	---	148
90	172	128	163
120	161	121	169
150	130	116	172
180	125	118	167
210	---	107	---
$LSD_{(0.05)}$	9	14	12

[z] LHRF = Lake Hogue Research Farm, Wiener, Ark.; NEREC = Northeast Research and Extension Center, Keiser, Ark.; and RREC = Rice Research and Extension Center, Stuttgart, Ark.

[y] A bushel of rice weighs 45 lb.

Table 4. Influence of nitrogen (N) fertilizer rate on the grain yield of Neptune rice at three locations during 2009.

N Fertilizer	Grain yield		
rate	LHRF[z]	NEREC	RREC
(lb N/acre)	------------------------------ (bu/acre[y])	------------------------------	
0	141	96	104
60	192	---	177
90	193	182	201
120	182	193	210
150	177	200	214
180	172	196	214
210	---	198	---
$LSD_{(0.05)}$	12	17	9

[z] LHRF = Lake Hogue Research Farm, Wiener, Ark.; NEREC = Northeast Research and Extension Center, Keiser, Ark.; and RREC = Rice Research and Extension Center, Stuttgart, Ark.

[y] A bushel of rice weighs 45 lb.

Table 5. Influence of nitrogen (N) fertilizer rate on the grain yield of Taggart rice at three locations during 2009.

N Fertilizer rate	Grain yield		
	LHRF[z]	NEREC	RREC
(lb N/acre)	------------------------------	(bu/acre[y])	------------------------------
0	129	70	95
60	172	---	159
90	181	158	187
120	168	152	200
150	163	153	210
180	160	154	208
210	---	142	---
$LSD_{(0.05)}$	8	14	7

[z] LHRF = Lake Hogue Research Farm, Wiener, Ark.; NEREC = Northeast Research and Extension Center, Keiser, Ark.; and RREC = Rice Research and Extension Center, Stuttgart, Ark.

[y] A bushel of rice weighs 45 lb.

Table 6. Influence of nitrogen (N) fertilizer rate on the grain yield of Templeton rice at three locations during 2009.

N Fertilizer rate	Grain yield		
	LHRF[z]	NEREC	RREC
(lb N/acre)	------------------------------	(bu/acre[y])	------------------------------
0	127	87	123
60	181	---	194
90	185	156	217
120	187	156	226
150	185	153	233
180	173	157	211
210	---	146	---
$LSD_{(0.05)}$	11	10	13

[z] LHRF = Lake Hogue Research Farm, Wiener, Ark.; NEREC = Northeast Research and Extension Center, Keiser, Ark.; and RREC = Rice Research and Extension Center, Stuttgart, Ark.

[y] A bushel of rice weighs 45 lb.

Table 7. Influence of nitrogen (N) fertilizer rate on the grain yield of Jazzman rice at three locations during 2009.

N Fertilizer	Grain yield		
rate	LHRF[z]	NEREC	RREC
(lb N/acre)	------------------------------ (bu/acre[y]) ------------------------------		
0	111	90	123
60	136	---	171
90	143	150	190
120	147	146	197
150	141	147	204
180	144	148	206
210	---	141	---
LSD$_{(0.05)}$	8	17	9

[z] LHRF = Lake Hogue Research Farm, Wiener, Ark.; NEREC = Northeast Research and Extension Center, Keiser, Ark.; and RREC = Rice Research and Extension Center, Stuttgart, Ark.

[y] A bushel of rice weighs 45 lb.

Table 8. Influence of nitrogen (N) fertilizer rate on the grain yield of JES rice at three locations during 2009.

N Fertilizer	Grain yield		
rate	LHRF[z]	NEREC	RREC
(lb N/acre)	------------------------------ (bu/acre[y]) ------------------------------		
0	163	85	134
60	204	---	185
90	193	125 ^{55}	210
120	176 ^{20}[x]	106 ^{67}	203
150	164 ^{27}	103 ^{84}	212
180	146 ^{35}	100 ^{92}	189
210	---	81 ^{90}	---
LSD$_{(0.05)}$	17	30	13

[z] LHRF = Lake Hogue Research Farm, Wiener, Ark.; NEREC = Northeast Research and Extension Center, Keiser, Ark.; and RREC = Rice Research and Extension Center, Stuttgart, Ark.

[y] A bushel of rice weighs 45 lb.

[x] Numbers in superscript to the side of the yield are lodging percentages.

Table 9. Influence of nitrogen (N) fertilizer rate on the grain yield of Clearfield CL151 rice at three locations during 2009.

N Fertilizer rate	Grain yield		
	LHRF[z]	NEREC	RREC
(lb N/acre)	------------------------------ (bu/acre[y]) ------------------------------		
0	163 ^{25}[x]	86	112
60	200	---	169
90	189 ^{5}	164	183
120	169 ^{38}	172 ^{22}	180
150	166 ^{75}	163 ^{42}	177
180	153 ^{88}	151 ^{42}	163
210	---	143 ^{78}	---
$LSD_{(0.05)}$	26	26	9

[z] LHRF = Lake Hogue Research Farm, Wiener, Ark.; NEREC = Northeast Research and Extension Center, Keiser, Ark.; and RREC = Rice Research and Extension Center, Stuttgart, Ark.

[y] A bushel of rice weighs 45 lb.

[x] Numbers in superscript to the side of the yield are lodging percentages.

Table 10. Influence of nitrogen (N) fertilizer rate on the grain yield of Clearfield CL111, CL142AR, and CL181AR rice at the Rice Research and Extension Center near Stuttgart, Ark., during 2009.

N Fertilizer rate	Grain yield		
	CL111	CL141AR[z]	CL181AR
(lb N/acre)	------------------------------ (bu/acre[y]) ------------------------------		
0	100	100	99
60	154	157	159
90	164	174	170
120	177	187	174
150	181	189	171
180	162	183	171
$LSD_{(0.05)}$	9	8	10

[z] CL142AR = STG051M1-01-113 and CL181AR = STG051M1-04-091.

[y] A bushel of rice weighs 45 lb.

Table 11. Influence of nitrogen (N) fertilizer rate on the grain yield of Bayer CropScience hybrid ArizeQM1003 rice at three locations in Arkansas during 2009.

N fertilizer rate					
Total N	N timing[z]		Grain yield		
rate	pf	bt	LHRF[y]	NEREC	RREC
(lb N/acre)			(bu/acre[x])		
0	0	0	188 ^{25w}	116	136
60	30	30	233 ^{10}	---	187
90	60	30	267 ^{5}	176	225
120	90	30	247	167 ^{45}	226
150	120	30	244	147 ^{33}	240
180	150	30	232 ^{5}	164 ^{35}	227
210	180	30	---	120 ^{20}	---
LSD$_{(0.05)}$			15	19	22

[z] pf = preflood; bt = late boot.

[y] LHRF = Lake Hogue Research Farm, Wiener, Ark.; NEREC = Northeast Research and Extension Center, Keiser, Ark.; and RREC = Rice Research and Extension Center, Stuttgart, Ark.

[x] A bushel of rice weighs 45 lbs.

[w] Numbers in superscript to the side of the yield are lodging percentages.

Table 12. Influence of nitrogen (N) fertilizer rate on the grain yield of experimental variety RU001124 rice at three locations during 2009.

N Fertilizer	Grain yield		
rate	LHRF[z]	NEREC	RREC
(lb N/acre)	(bu/acre[y])		
0	128 ^{5x}	48	98
60	200 ^{38}	---	161
90	182 ^{88}	131	176
120	128 ^{93}	151 ^{13}	177
150	110 ^{100}	172 ^{45}	176
180	82 ^{100}	155 ^{55}	173
210	---	131 ^{65}	---
LSD$_{(0.05)}$	39	34	9

[z] LHRF = Lake Hogue Research Farm, Wiener, Ark.; NEREC = Northeast Research and Extension Center, Keiser, Ark.; and RREC = Rice Research and Extension Center, Stuttgart, Ark.

[y] A bushel of rice weighs 45 lb.

[x] Numbers in superscript to the side of the yield are lodging percentages.

Table 13. Influence of nitrogen (N) fertilizer rate on the grain yield of Arkansas experimental rice variety RU0801076 at the Rice Research and Extension Center near Stuttgart, Ark., during 2009.

N fertilizer rate	Grain yield
(lb N/acre)	(bu/acre[z])
0	109
60	169
90	188
120	191
150	196
180	194
$LSD_{(0.05)}$	12

[z] A bushel of rice weighs 45 lb.

Alkaline Hydrolyzable-Nitrogen Changes with Soil Depth: Implications for Calibration of Predicted Nitrogen Rates

T.L. Roberts, R.J. Norman, N.A. Slaton, and C.E. Wilson, Jr.

ABSTRACT

Alkaline hydrolyzable-N (AH-N) quantified by the Illinois Soil Nitrogen Test (ISNT) or Direct Steam Distillation (DSD) may index potentially mineralizable-N in the soil. Limited success has been achieved utilizing the ISNT to predict corn (*Zea mays* L.) yield response when soils are sampled to a depth of 12 in. (30 cm) and a strong correlation of ISNT to total N (TN) has raised concerns over the sensitivity of the method in determining potentially mineralizable-N. A study was implemented to determine the effects of site and soil depth on AH-N. Soil samples were collected from 0 to 24 in. (0 to 45 cm) in 6-in. (15-cm) depth increments and analyzed for AH-N (ISNT and DSD) and TN. Analysis of variance for AH-N showed a significant site × soil depth interaction. Alkaline hydrolyzable-N ranged from 22 to 280 mg N kg soil^{-1} and the highest values were not always in the top 6 in. (15 cm) of the soil. Alkaline hydrolyzable-N accounted for 11% to 38% of soil TN and was variable across sites and depths. Variation in AH-N and the fraction of TN quantified as AH-N with site and soil depth indicate the importance of proper sampling depth (i.e., to the rooting depth of a given crop) for correlation and calibration of crop response using either the ISNT or DSD. Significant changes in AH-N with depth could influence crop-available N and thus the reliability of a soil test to predict crop response to N-fertilization.

INTRODUCTION

Plant uptake and assimilation of N is highly dependent on the mineralization of organic-N and the presence of both NH_4^+ and NO_3^- in the soil solution. Correlation and calibration of crop N response has always been an important focus of soil fertility research and will continue to be as agricultural production costs and economic uncertainty increase. Research has shown that subsoil nutrient levels can influence crop yield and increase the predictive capability of soil-test methods to predict crop response to nutrient additions. Subsoil K and P levels have been shown to influence the yield of both corn and soybean [*Glycine max* (L.) Merr.] (Mallarino and Ul-Haq, 1997). Potentially mineralizable-N in the subsoil (>6 in.) can be a significant source of plant-available N as many crops have rooting depths greater than 6 in. (15 cm). Previous studies have documented corn roots growing to depths of 24 to 36 in. (45 to 60 cm) (Laboski et al., 1998) and similar results have been found for rice (*Oryza sativa* L.) (Beyrouty et al., 1987). A better understanding of potentially mineralizable-N in the subsoil may clarify why at some sites the N uptake and/or yield does not correlate well when the AH-N is used at just the 0 to 6 in. (0 to 15 cm), 6 to 12 in. (15 to 30 cm), or 0 to 12 in. (0 to 30 cm) depths. The forms of organic-N and exchangeable NH_4-N quantified by ISNT and DSD can be greatly influenced by cropping systems and soil texture. These compounds may also be adsorbed or leached depending on the soil characteristics such as pH, clay content, and OM. We hypothesized that AH-N varies with depth and is therefore not a constant fraction of TN. Thus, the following objectives were developed to determine the relationship between AH-N and soil depth: 1) determine the influence of site and soil depth on AH-N for silt loam soils; and 2) compare the fraction of TN quantified as AH-N across depths.

METHODS AND MATERIALS

Sixteen agricultural sites located on silt loam soils across the state of Arkansas were selected to represent a range of soil characteristics and previous crops. Sites included both agricultural experiment station and commercial production fields that were sampled in either April or May of each year prior to N fertilization. A minimum of four soil cores (1-in. diameter) were taken to form a composite sample at depth increments of 0 to 6 in. (0 to 15 cm), 6 to 12 in. (15 to 30 cm), 12 to 18 in. (30 to 45 cm), and 18 to 24 in. (45 to 60 cm), respectively, and replicated four times within a field for a total of 16 samples per site (4 depths × 4 replications). The University of Arkansas Diagnostic Laboratory (Fayetteville, Ark.) analyzed soil samples for TN using an Elementar CN Variomax (Elementar Americas Inc., Mt Laurel, N.J.) according to the procedure of Nelson and Sommers (1996). Alkaline hydrolyzable-N was determined using the ISNT (Khan et al., 2001) and 10 *M* NaOH DSD methods (Roberts et al., 2009). All statistical analyses were carried out using JMP 7.0 (SAS Institute, Inc., Cary, N.C.). The treatment structure for all statistical analysis was a split-plot design with site representing the main-plot factor and soil depth representing the split-plot factor. Analysis of variance was conducted to determine the effects of site and soil depth on AH-N as well as the ratio of AH-N to TN and significant differences reported at the $\alpha = 0.05$ level.

RESULTS AND DISCUSSION

The interaction between site and soil depth was significantly different for alkaline hydrolyzable soil-N determined by ISNT and DSD suggesting that location (i.e. soil series, climate, previous crop, parent material, etc.) influences the rate and direction of change in AH-N with depth. Although there was no consistent relationship between AH-N and depth across all sites, the ISNT and DSD quantified significantly greater concentrations of N in the 0 to 6 in. (0 to 15 cm) depth increment compared to the 6 to 12 in. (15 to 30 cm) increment at all sites except 2 and 11 (ISNT only) (Fig. 1). Alkaline hydrolyzable-N quantified by the ISNT or DSD below 12 in. (30 cm) varied and increased, decreased, or remained constant compared with the concentrations quantified in the 6 to 12 in. (15 to 30 cm) increment within each site. For some soils, the AH-N concentrations quantified by the ISNT (sites 7 and 8) and DSD (sites 2 and 6) in the 0 to 6 in. (0 to 15 cm) depth were similar to concentrations in soil depths below 12 in. (30 cm). Alkaline hydrolyzable-N concentrations at depths >12 in. (30 cm) cannot be accurately predicted based solely on the AH-N in the 0 to 6 in. (0 to 15 cm) depth of the soil. When an individual soil depth was considered, AH-N was highly variable from site to site indicating that it may be influenced by long-term crop rotations, soil manipulation (i.e., land leveling), tillage and naturally inherent variations in N cycling. If soil depths >6 in. (15 cm) influence crop response to N fertilizer, then a soil profile similar to site 2 may help to explain why crops grown on some soils do not respond to additions of N. For example, the 6 to 12 in. (15 to 30 cm) depth and 12 to 18 in. (30 to 45 cm) depth of soil at site 2 had a significantly higher quantity of AH-N and the 18 to 24 in. (45 to 60 cm) depth was not significantly different from the 0 to 6 in. (0 to 15 cm) depth. Mulvaney et al. (2006) highlighted the importance of subsoil fertility on ISNT calibration, but unfortunately potentially available N from soil below 12 in. (30 cm) has been largely or completely ignored. Crop rooting depth should be a primary factor when determining sampling depths for correlation and calibration of AH-N for yield and crop response to N fertilizer.

The percentage of TN quantified as AH-N was highly variable and ranged from 8% to 38% across all sites and depths (Fig. 2). Analysis of variance for the percentage of TN quantified as AH-N showed a significant site by soil depth interaction for both the ISNT and DSD. Differences in the percentage of TN quantified as AH-N were proportional to the differences in recovery by the ISNT and DSD methods within a site. The percentage of TN quantified as AH-N was greatest for site 2 at depths below 6 in. (15 cm) (Fig. 2) and may be accounted for in the high levels of exchangeable NH_4-N, but the N quantified by DSD represented as much as 38% of the TN in the 6 to 12 in. (15 to 30 cm) depth. The percentage of TN quantified by DSD for sites 9 and 10 were almost twice the percentage for the ISNT method at soil depths below 6 in. (15 cm). Concentrations of AH-N quantified by DSD were greatest in soil at the sites with the both the highest (site 2) and lowest (site 10) TN concentrations and in several cases represented almost one-third of the TN for that depth. In one-half of the sites, the percentage of TN quantified by ISNT was similar in trend and magnitude to that quantified by DSD, but in the other eight sites (9 to 16) the fractional AH-N recovery was highly variable with no distinct trend.

The percent recovery of TN as AH-N by the ISNT in the top 6 in. (15 cm) of the soil profile averaged 13.4%, which is similar to the percentage reported by Laboski et al. (2008). Comparison of AH-N fractions below 6 in. (15 cm) cannot be made as previous studies have not reported TN at 6 to 12 in. (15 to 30 cm) nor has soil sampled at depths greater than 12 in. (30 cm) been analyzed for AH-N. It is important to note that within a profile, the amount of TN quantified as AH-N is often inversely proportional to TN. In soil depths, such as the top 6 in. (15 cm), where TN is high the resulting ratios are often low. For most sites, except where soybean was the previous crop, the ratio of AH-N to TN is numerically greater at depths below 6 in. (15 cm) where TN decreases (Fig. 2). These results suggest that the N in the top 6 in. (15 cm) of the soil is primarily found in organic-N forms that are not readily available for mineralization. High rates of biological activity and humification in the topsoil result in N conversion to more recalcitrant forms, which do not readily mineralize. Uptake and utilization of organic-N at depths >6 to 12 in. appear to be highly feasible, especially in areas of active rooting.

Alkaline hydrolyzable-N as measured by the ISNT or DSD methods are significantly influenced by the interaction of site and soil depth. The ISNT and DSD have been investigated due to their use as plant-available N indices and ability to predict crop response to N fertilizer. These data identify the potential importance of N found at depths greater than 12 in. (30 cm) for crop growth. Alkaline hydrolyzable-N has been proposed as a predictor of potentially mineralizable-N and based on these findings can be significantly impacted by the location and the depth of soil being analyzed.

SIGNIFICANCE OF FINDINGS

With the concurrent development of N-ST*R, a soil-based N test for rice production in Arkansas, the importance of soil sampling depth on the success of a particular soil testing method has been highlighted. Traditionally rice has been thought of as a shallow rooted crop, but previous work has shown that rice roots can grow and access nutrients at depths much greater than 6 in. (15 cm). Correlation and calibration of crop response to potentially mineralizable-N or AH-N must be accomplished at the same soil depth as the crop's rooting depth in order to correctly evaluate the method's predictive ability. Changes in the fraction of AH-N with soil depth that are in contrast with changes in TN may suggest the need for depths to be weighted differently based on their relative magnitude of potentially mineralizable-N. Previous crops may also influence the ratio of AH-N to TN and should be taken into consideration when comparing different crop rotations as the available-N may change even though TN may not. The changes in AH-N with depth and changes in the fraction of AH-N to TN explain the need for 0 to 18 in. (0 to 45 cm) sample depths for N-ST*R on silt loam soils, and help to strengthen N-ST*R's predictive ability ensuring that the correct N fertilizer rates will be recommended for rice.

ACKNOWLEDGMENTS

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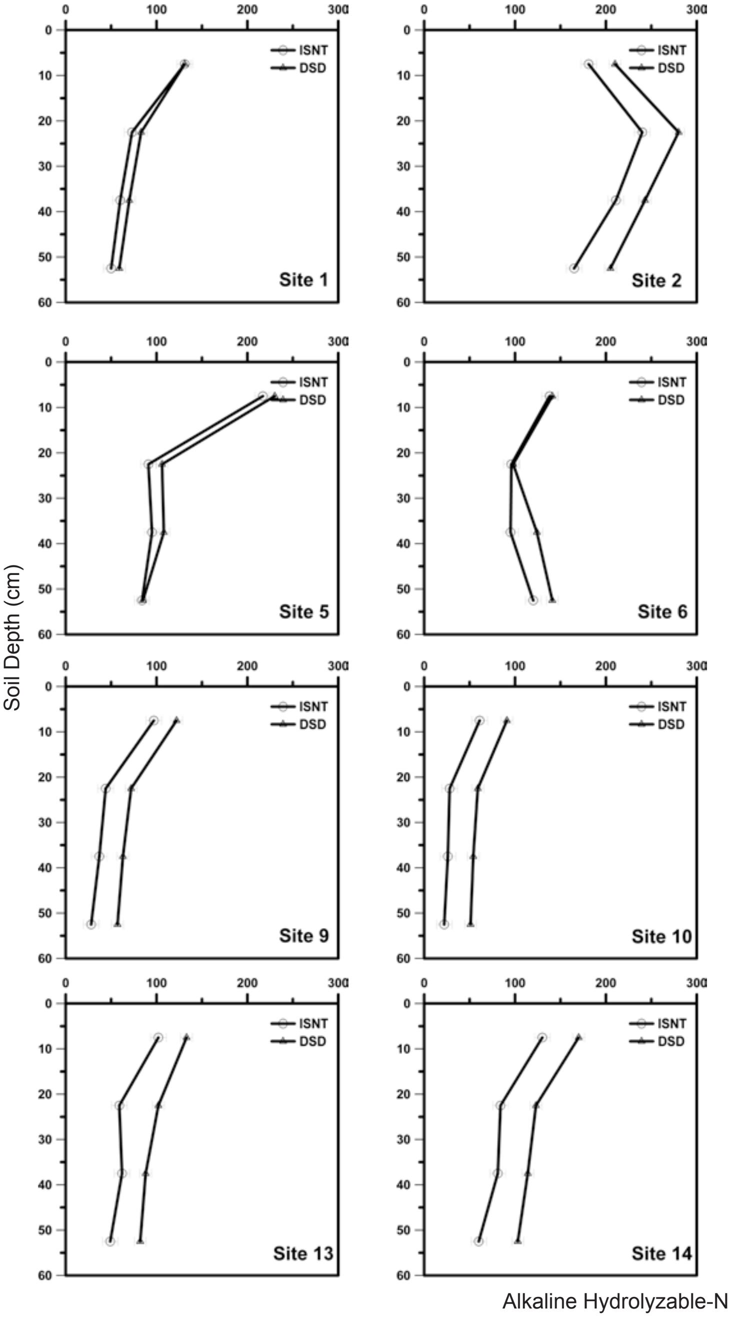
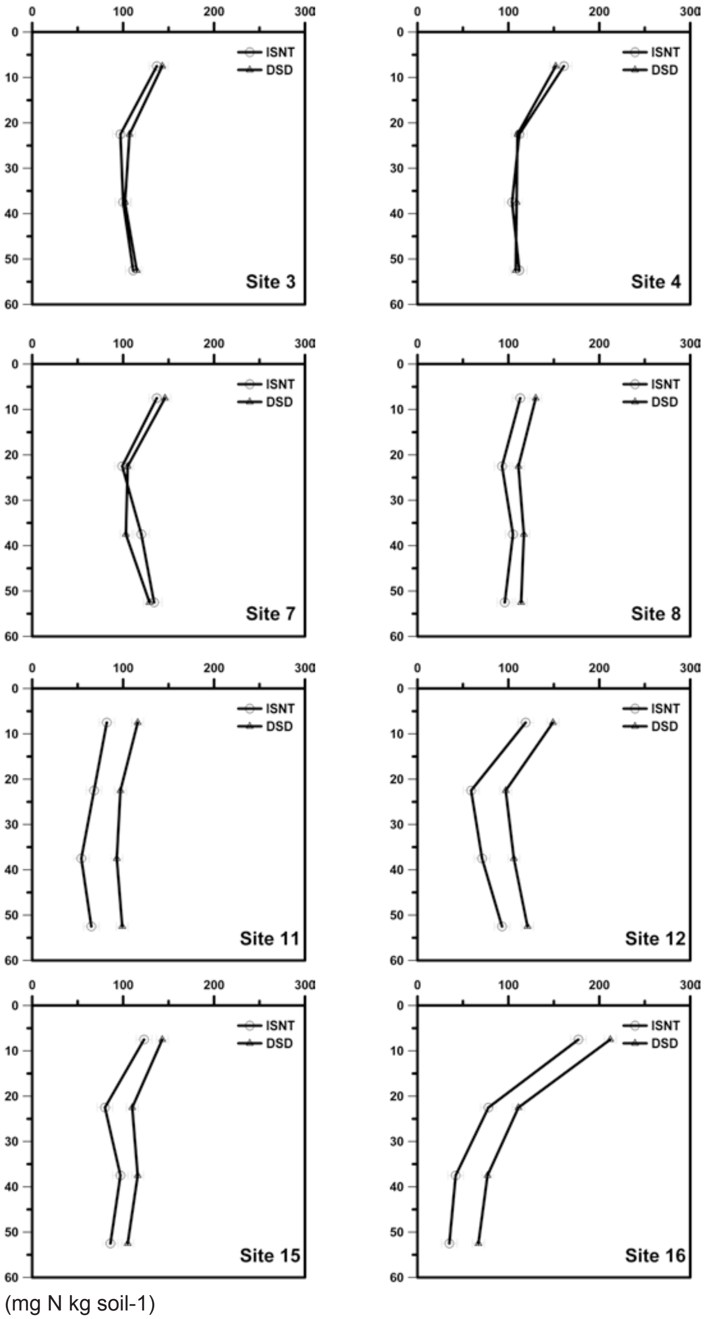


Fig. 1. Alkaline hydrolyzable-N (AH-N) determined Direct Steam Distillation (DSD) as influenced by soil depth for



by the Illinois Soil Nitrogen Test (ISNT) and
each site. Error bars represent one standard deviation.

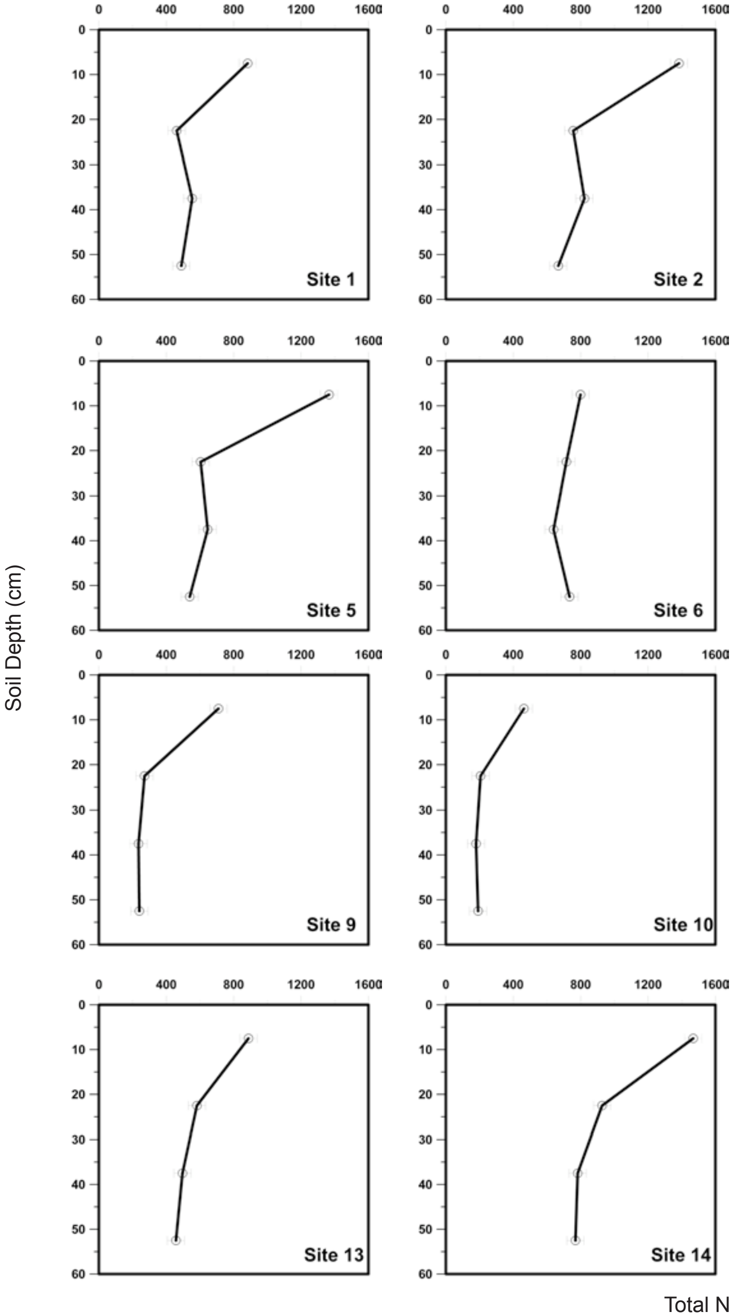
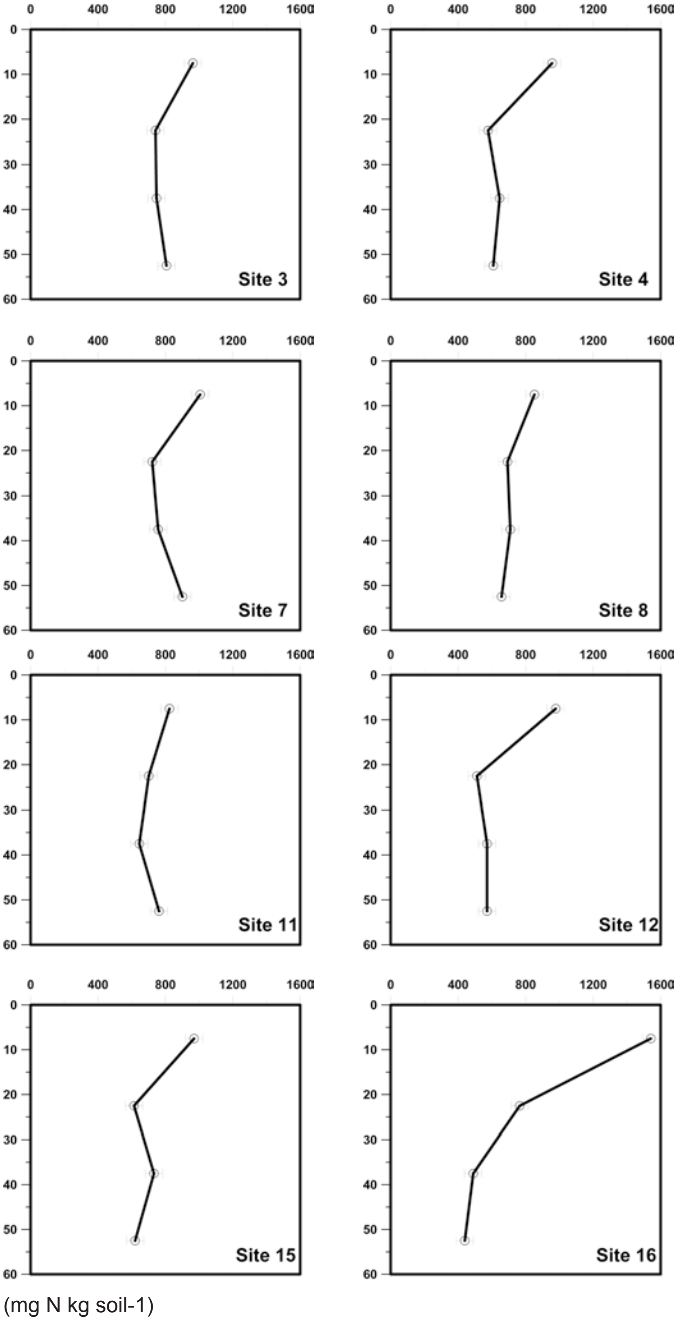


Fig. 2. Percentage of total soil N (TN) as influenced by soil depth



for each site. Error bars represent one standard deviation.

N-ST*R- A Soil-Based Nitrogen Test for Fertilizer Recommendations in Arkansas Rice Production

T.L. Roberts, R.J. Norman, N.A. Slaton, C.E. Wilson, Jr., and W.J. Ross

ABSTRACT

Nitrogen (N) response trials were conducted in Arkansas to evaluate alkaline-hydrolyzable N quantified by Direct Steam Distillation (DSD) in measuring soil N availability and as a precision N management tool. Field studies were conducted on 26 silt loam soils at experiment stations and producer fields across the state. Six N fertilizer rates ranging from 0 to 180 lb N/acre were applied in split applications in a randomized complete block design with four replications. Total N uptake and grain yield were used for correlation and calibration of the Nitrogen-Soil Test for Rice (N-ST*R). Percent relative grain yield and N fertilizer rate to achieve 95% relative grain yield was regressed against the mean N-ST*R values for the 0 lb N/acre rate plots at each location. Currently, 26 site-years have been used to develop N-ST*R for rice grown on silt loam soils with significant relationships between percent relative grain yield and N rate to give 95% relative grain yield. Results show a strong correlation between percent relative grain yield and N-ST*R at the 0- to 18-in. depth. The coefficients of determination increased for percent relative grain yield and N rate to give 95% relative grain yield as depth increased until 18 in., but then dropped significantly at the 0- to 24-in. depth. Coefficients of determination >0.80 at the 0- to 18-in. depth indicate that the incorporation of N-ST*R for N fertilizer recommendations would allow site-specific N management while lowering costs and environmental impacts.

INTRODUCTION

Costs associated with rice production have continued to rise, primarily in the form of nitrogen (N) fertilizer. 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 on the soil's ability to supply N should be considered. New soil testing methods such as direct steam distillation (DSD) are able to measure soil N availability, but are unable to consistently predict corn yield. There have been several papers that focused on alkaline-hydrolyzable N and its use for corn N recommendations (Mulvaney et al., 2001; Williams et al., 2007), but no research has been conducted for rice. Researchers have experimented with soil-based N tests as long as there has been soil fertility research. Although some methods have shown promise for rice grown in a greenhouse (Wilson et al., 1994), nothing has stood out as a solid method for predicting rice response to N fertilizer. Identification of a simple soil test to measure the amount of available soil N is becoming more and more important and will be essential for the long-term sustainability of Arkansas rice production. Benefits of a soil N test are not just about optimizing economic or agronomic returns, but making environmentally sound N fertilizer decisions. The objective of this study was to evaluate the use of DSD for rice production on silt loam soils in Arkansas.

METHODS AND MATERIALS

Field experiments were conducted in Arkansas from 2005 to 2008 on several silt loam soils around the state to evaluate the ability of DSD to predict N response characteristics in rice. Studies conducted on experiment stations were seeded with 'Wells' and producer fields were chosen with cultivars that had similar N fertilizer requirements and yield potential (i.e., 'Francis'). On station, rice was seeded at ~100 lb/acre in nine-row plots (7-in. spacing) of 15 ft in length. The rice was grown upland until the 4- to 5-leaf growth stage at which time a permanent flood (2- to 4-in. depth) was established and maintained until maturity. Nitrogen response trials were randomized complete block designs with four replications and fertilizer rates ranging from 0 to 180 lb N/acre as a 2-way split application. For each of the plots receiving N, the majority was applied prior to flooding with a small portion applied at midseason. Soil cores were taken prior to flooding from the 0 lb N/acre treatments in 6-in. increments to a depth of 24 in. and analyzed using DSD. 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. Percent relative grain yield was determined by dividing the 0 lb N/acre plot yield by the maximum yield at that location, and the N rate that resulted in 95% of maximum yield was used for calibration procedures. Percent relative grain yield was correlated to the average DSD soil-test N value for each depth (0 to 6 in., 0 to 12 in., 0 to 18 in., and 0 to 24 in.). Calibration of N-ST*R was achieved by regressing the N rate to achieve 95% relative grain yield against the average DSD soil-test N value for each depth (0 to 6 in., 0 to 12 in., 0 to 18 in., and 0 to 24 in.). Correlations were determined using JMP 7.0 (SAS Institute, 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 150 lb N/acre. This number is achieved statistically using the mean N-rate to achieve maximum yield over several locations around the state. 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 more precise soil-based approach to N fertilizer recommendations was evaluated.

Correlation of individual depth increments of 0 to 6 in., 0 to 12 in., 0 to 18 in., and 0 to 24 in. resulted in a significant relationship between relative grain yield and DSD at the $p = 0.01$ level (Table 1). Coefficients of determination suggest that the best sampling depth was 0 to 18 in. for maximum predictive value. Coefficients of determination for relative grain yield versus DSD increased with depth until 0 to 18 in. where a decrease was seen at the 0 to 24-in. increment (Table 1). The best relationship between relative grain yield and the soil-based N test not being obtained until the 0 to 18 in. depth suggests that rice can access and utilize soil N from a large portion of the soil profile. An improvement in the precision of DSD to predict relative grain yield as the sampling depth increases was observed and conflicts with traditional thought that the majority of nutrients are taken up from the top 6 in. of the soil profile. Relative grain yield appears to be highly dependent on soil N mineralization potential and sub-soil N availability.

Calibration of a soil-based N test is the most important step and is the most critical in determining its success. Soil test calibration involves using a soil test result to predict the amount of a particular nutrient that needs to be applied in order to achieve maximum yields. For purposes of this evaluation, the N rate to achieve 95% relative grain yield was regressed against results from the soil-based N test to determine if they were capable of predicting N fertilizer needs. Calibration of each depth has been presented here for comparison purposes. Traditional sampling depth is 0 to 6 in. and although there is a statistically significant relationship at this soil depth, the predictive ability is quite low with an R^2 of 0.56 (Fig. 1). As the soil sampling depth increases, there is a corresponding increase in the coefficients of determination with the 0- to 12-in. depth resulting in an $R^2 = 0.69$ (Fig. 2). The strongest correlation is presented in Fig. 3 where the N rate to give 95% relative yield is regressed against the DSD value at the 0- to 18-in. soil depth ($R^2 = 0.89$). Similar to the results obtained with relative grain yield (Table 3), the predictive quality of the soil test increased with depth until the 0- to 18-in. depth with a decrease at the 0- to 24-in. depth (Fig. 4). The 0- to 18-in. depth clearly had the best correlation and predictive ability when comparing all of the depths (Table 2). The highest correlation for relative grain yield (Table 1) was also seen at the 0- to 18-in. depth increment, which strongly supports the calibration data (Table 2). It is very important that the correlation for relative grain yield and the calibration of N fertilizer rate have similar relationships at the same depths within the soil profile.

Initial results indicate the strong need for a soil-based N test for fertilizer recommendations in Arkansas. Based on the results of this study, producers may be applying more N fertilizer than is necessary to achieve top yields in their particular field(s), but this problem will only become more of an issue as N fertilizer prices continue to rise. Saving money by applying less N is not the only concern, but an emphasis should also be placed on the potential environmental impacts of applying too much N fertilizer. To insure the continued success of Arkansas rice producers, N-ST*R should be incorporated for use on silt loam soils as a precision N management tool. N-ST*R will allow site-specific N fertilizer recommendations while avoiding excess N application and lowering potential disease problems, but ultimately it will keep more money in producer pockets.

SIGNIFICANCE OF FINDINGS

The long-term sustainability of Arkansas rice production hinges on the smart and efficient use of N fertilizer. Costs associated with all aspects of rice production have been on the rise, but the cost of urea has more than doubled within the last decade and can represent a significant portion of the producer inputs. Recommendations are based on the assumption that a few sites within the state represent the majority of silt loam soils across the state. Extreme differences in N quantity and availability can exist within a single farm on the same silt loam soil. A better understanding of N availability and how it impacts rice yield is an important step toward insuring the continued success of Arkansas rice producers. The results presented here show the potential for N-ST*R specifically for rice produced on silt loam soils within Arkansas. The adoption of N-ST*R for use in N fertilizer recommendations could potentially save producers money by managing N fertilizer needs on a field to field basis. As demonstrated above, the current recommendation suggests that many fields are receiving more N fertilizer than required to maximize yields, identifying the potential for increased incidence of disease and higher total input costs. Site-specific N management is a primary goal for all crops and is starting to become a reality for Arkansas rice producers thanks to the development of N-ST*R.

ACKNOWLEDGMENTS

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Table 1. Comparison of N-ST*R depth increments and the corresponding prediction of relative rice grain yield for 26 sites in Arkansas.

	N-ST*R		
Soil depth	Slope	Intercept	R^2
----(in.) ---			
0-6	0.35	4.91	0.50
0-12	0.61	-15.17	0.60
0-18	0.93	-44.58	0.73
0-24	0.67	-13.13	0.57

Table 2. Comparison of N-ST*R depth increments and the corresponding prediction of the N rate to give 95% relative rice grain yield for 26 sites in Arkansas.

	N-ST*R		
Soil depth	Slope	Intercept	R^2
----(in.) ---			
0-6	-0.86	218	0.56
0-12	-1.65	294	0.69
0-18	-1.81	295	0.89
0-24	-1.41	245	0.73

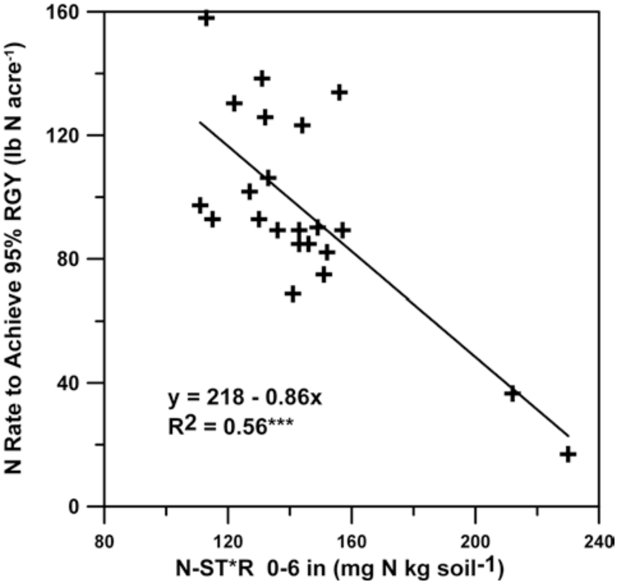

Fig. 1. Calibration of N rate to achieve 95% relative rice grain yield versus N-ST*R for the 0- to 6-in. depth increment.

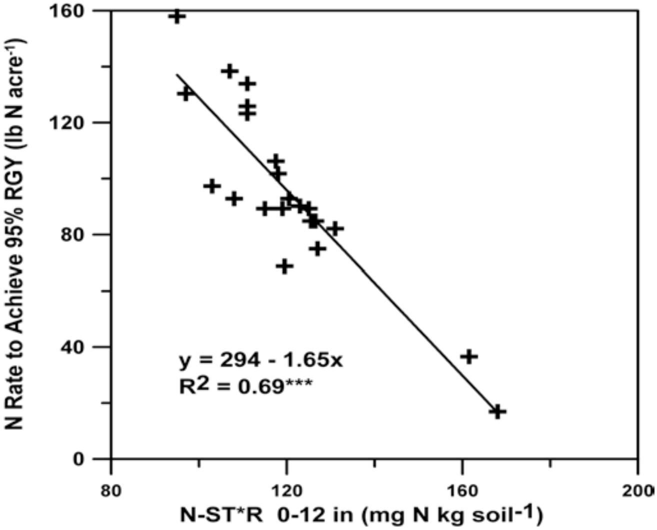

Fig. 2. Calibration of N rate to achieve 95% relative rice grain yield versus N-ST*R for the 0- to 12-in. depth increment.

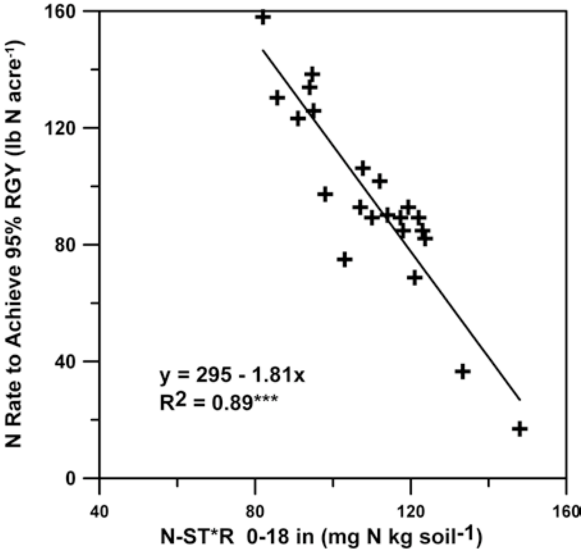

Fig. 3. Calibration of N rate to achieve 95% relative rice grain yield versus N-ST*R for the 0- to 18-in. depth increment.

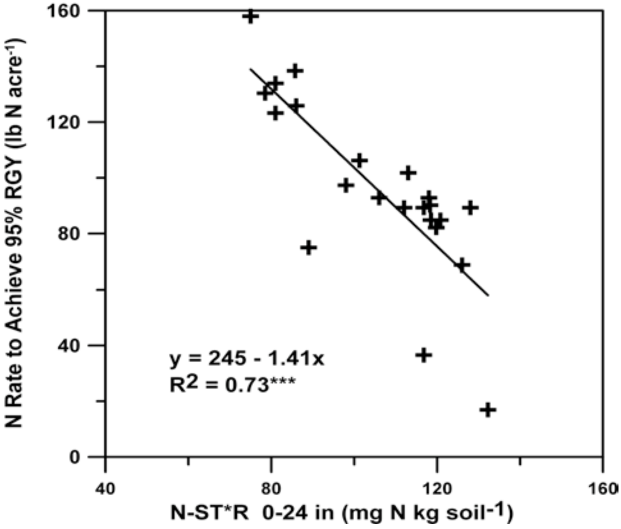

Fig. 4. Calibration of N rate to achieve 95% relative rice grain yield versus N-ST*R for the 0- to 24-in. depth increment.

RICE CULTURE

Rice Response to Phosphorus and Potassium Fertilization Time

N.A. Slaton, R.E. DeLong, R.J. Norman, S.D. Clark, and B.R. Golden

ABSTRACT

One of the most common questions from growers is whether phosphorus (P) and/or potassium (K) fertilizers can be applied in the fall and winter, four to six months before rice is planted. Our research objective was to evaluate rice yield and nutrient uptake response to P and K fertilizers applied in December, February, and April (planting) on a soil having below optimum soil-test P and K levels. Phosphorus- and K-fertilizers were broadcast applied to the soil surface at rates of 0, 45, and 90 lb K_2O or P_2O_5/acre in December 2008, February 2009, and April 2009. Rice growth, nutrient uptake, and grain yield were measured. Rice grain yields were increased significantly only by K fertilizer rate. However, tissue concentrations and aboveground uptake of P and K at selected growth stages suggested that fertilizer P and K were taken up with equal efficiency regardless of the time of fertilizer application. Based on the results from this one trial, P and K fertilizer rates appear to be more important than the time of application.

INTRODUCTION

Phosphorus (P) and potassium (K) fertilizers are usually applied within a few days or weeks before rice is planted. A sufficient amount of P or K fertilizer applied from planting to the early tillering stage generally produces similar rice yield increases on responsive soils. However, rice yield response to P or K diminishes when the time of application is delayed until reproductive growth. The primary focus of recent research has been to correlate and calibrate soil-test based fertilizer recommendations for these nutrients and determine how to ameliorate P and K deficiencies during the season. These research efforts have increased our confidence in P and K fertilization recommendations and allow us to now focus on other questions that require research-based answers.

One of the most common questions in recent years has been whether P and/or K fertilizers can be applied in the fall and winter, four to six months before rice is planted. As a general rule, we have discouraged growers from fall applying P and K fertilizers due to soil reactions (i.e., fixation) that may reduce plant availability of fertilizer nutrients across time and the increased risk of nutrient loss via erosion, runoff, and/or leaching. Furthermore, we have occasionally observed P deficiency in rice fields that reportedly received fall-applied P fertilizer. Knowledge of how nutrient application time influences crop response to fertilization will become increasingly important as poultry litter use increases and fertilizer prices fluctuate between the fall and spring. Our research objective was to evaluate rice yield and nutrient uptake response to P and K fertilizers applied in December, February, and April (planting) on soil having below optimum soil-test P and K levels.

PROCEDURES

Research was established on a soil mapped as a Calloway silt loam at the Pine Tree Research Station. A field, cropped to soybean in 2008, was tilled and floated in November 2008 to prepare a level seedbed. Adjacent research areas, one each for P and K, were flagged to define individual plot boundaries (7-ft wide × 25-ft long). In April 2009, composite soil samples were collected (0-to 4-in.) from plots that had received no P or K fertilizer in each trial area. Composite soil samples were analyzed for soil pH (1:2 soil: water mixture), Mehlich-3 extractable soil nutrients, and soil organic matter content (Table 1).

Phosphorus- (as triple superphosphate) and K-fertilizer (as muriate of potash) treatments were broadcast applied to the soil surface at rates of 0, 45, and 90 lb K_2O or P_2O_5/acre on 14 December 2008, 6 February 2009, and 22 April 2009. The K research area received 90 lb P_2O_5/acre and the P research area received 120 lb K_2O/acre as muriate of potash on 22 April 2009. Zinc fertilizer (10 lb Zn/acre as $ZnSO_4$) was broadcast onto the soil surface of each research area. 'Wells' rice (100 lb/acre, 7.5-in. wide rows) was drill-seeded into an undisturbed (i.e., stale) seedbed on 22 April 2009. Urea fertilizer was applied on 3 June 2009 to supply 130 lb N/acre and a 4-in. deep flood was established on 4 June. Rice management with respect to irrigation and weed control was performed following University of Arkansas Cooperative Extension Service guidelines.

Rice plant samples were collected from a 3-ft length of the first inside row at the midtillering (14 June) stage in the P trial and the late boot stage (21 July) in the K trial to evaluate how time and rate of fertilizer application affected rice uptake of P and K fertilizer, respectively. Plant samples were oven dried to a constant weight, weighed for dry matter accumulation, ground to pass a 2-mm sieve, and a subsample was digested in 30% H_2O_2 and concentrated HNO_3 to determine tissue nutrient concentrations.

Each experiment was a randomized complete block design with a 2 (fertilizer rate) × 3 (application month) factorial treatment arrangement compared to a no fertilizer (P or K) control. Each treatment was replicated six times and each replicate contained two no fertilizer control plots. All statistical analyses were performed with the GLM procedure in SAS v9.2 (SAS Institute, Cary, N.C.) with significant differences interpreted when $P<0.10$ for yield and nutrient concentration data.

RESULTS AND DISCUSSION

Rice Response to K Fertilization

The soil had a 'Medium' soil-test K level (91 to 130 ppm K) with the average soil-test K (Table 1) being very near the critical soil K concentration suggesting that if rice yield increase occurred from K fertilization, the increase would likely be small. Dry matter accumulation at the late boot stage was not affected by application rate (P=0.3222), time (P=0.9755), or their interaction (P=0.9787, Table 2). Whole-plant K concentrations were also unaffected by K rate (P=0.3687), application time (P=0.6219) or their interaction (P=0.4835), but showed a distinct trend for rice receiving no K to have numerically lower K concentrations and aboveground K uptake than rice receiving K. Single-degree-of-freedom contrasts showed that rice receiving no K had significantly lower K concentrations and uptakes than rice receiving K (data not shown). Rice grain yield was unaffected by K application time (P=0.4501) and the rate by time interaction (P=0.2982), but was affected by K rate, averaged across application times. The yield of rice fertilized with 90 lb K_2O/acre was 7% greater than rice receiving no K.

Rice Response to P Fertilization

The soil had a 'Very Low' soil-test P level (<16 ppm P) and a pH of 6.5 suggesting that rice may benefit from P fertilization. However, soil-test P is not highly correlated with rice yield response to P fertilization. A visual inspection of plant growth after flooding suggested there was no positive benefit from P fertilization on this soil. Dry matter accumulation at the midtillering stage confirmed the visual assessment as dry matter was not affected by P application rate (P=0.7254), time (P=0.8614), or their interaction (P=0.3762, Table 3). However, both P rate and the interaction between application time and rate showed significant differences for tissue P concentrations and total P uptake. Tissue P concentration and uptake increased numerically or statistically as P rate increased (Table 4), but the magnitude of the increase among P rates varied among P application times. The significant interaction provided no clear evidence indicating a possible advantage or disadvantage of one application time over another. The means for each application time, averaged across the 45 and 90 lb P_2O_5/acre rates, showed a non-significant trend for P concentration and uptake to increase numerically as the time of P application before seeding increased. The mean tissue P concentration of rice receiving no P fertilizer was 0.168% P, which would be considered low, but not P deficient. Rice grain yield was not affected by P fertilization rate (P=0.2001), time of application (P=0.8656), or their interaction (P=0.7267) in this trial.

SIGNIFICANCE OF FINDINGS

Rice growth, nutrient uptake, and grain yield were largely unaffected by the time of fertilizer application and only K fertilizer rate had a nominal, albeit significant influence on rice yield. Tissue P and K concentrations were numerically similar among fertilizer application times and always higher than that of rice receiving no P or K fertilizer. Despite the lack of significant yield benefits from P fertilization and only a nominal yield increase from K fertilization, the results from this single-site year of research suggest that P and K fertilizer can be applied 3 to 5 months before rice is planted provided that the correct rate is applied. However, growers are still advised to use caution in applying P and K fertilizers months in advance of planting as deficiencies of these two nutrients have been observed in fields that received fall and, sometimes, spring fertilizer applications. These instances may have been due to fixation of the applied nutrient during the interval between the fertilizer application and plant use or may have simply been due to the application of an insufficient rate.

ACKNOWLEDGMENTS

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Table 1. Selected soil chemical property means (0- to 4-in. depth) from samples collected in April 2009 from soil receiving no P and K fertilizer.

	Soil	Mehlich-3 extractable soil nutrient concentrations[y]								
Site	pH[z]	P	K	Ca	Mg	S	Fe	Mn	Zn	Cu
		(ppm)								
P trial	6.5	11	105	995	261	9	164	385	2.5	1.4
K trial	6.6	8	96	1023	271	9	150	368	2.2	1.1

[z] Soil pH measured in a 1:2 soil:water mixture.

[y] All values are the mean of six or more composite samples taken from the 0-to 4-in. depth from plots designated to receive no P or K fertilizer.

Table 2. Whole-plant K concentration and uptake at early heading and grain yield of rice as affected by K application rate, averaged across K application times.

K rate	Dry matter	K concentration	K uptake	Grain yield
(lb K_2O/acre)	(lb/acre)	(% K)	(lb K/acre)	(bu/acre)
0	9157	1.22	112	155
45	8727	1.47	130	159
90	9013	1.54	138	165
LSD0.10	NS[z]	NS	NS	6
p-value	0.3222	0.3687	0.2215	0.0686

[z] NS, not significant (*P* > 0.10).

Table 3. Whole-plant P concentration and uptake at the midtillering stage and grain yield of rice as affected by P application rate, averaged across P application times.

P rate	Dry matter	Grain yield
(lb P_2O_5/acre)	(lb/acre)	(bu/acre)
0	1282	171
45	1419	178
90	1394	174
LSD0.10	NS[z]	NS
p-value	0.7254	0.2001

[z] NS, not significant (*P* > 0.10)

Table 4. Whole-plant P concentration and uptake by rice at the midtillering stage as affected by the P rate by application time interaction.

	P concentration			P uptake		
P rate	Dec08	Feb09	Apr09	Dec08	Feb09	Apr09
(lb P_2O_5/acre)		(% P)			(lb P/acre)	
0		0.166			2.1	
45	0.200	0.182	0.193	2.8	2.5	2.9
90	0.224	0.225	0.197	3.1	3.3	2.6
LSD0.10		0.019			0.5	
p-value		0.0855			0.0588	

Rice Response to Phosphorus and Potassium Fertilization

N.A. Slaton, R.J. Norman, R.E. DeLong,
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ABSTRACT

Phosphorus (P) and potassium (K) fertilizers are often needed to maintain soil fertility and/or maximize agronomic yield of rice grown on silt loam soils. This report describes five experiments that were conducted on silt loam soils in 2009 with objectives of examining rice growth and yield responses to P and K fertilizer source, rate, and/or time of application. One trial also evaluated differences in K uptake and yield of a conventional rice cultivar and hybrid rice as affected by K fertilizer rate. The findings from these trials indicate that there is little or no difference in P availability between TSP and DAP, that soils with *low* to *medium* soil-test K values required annual K rates >40 lb K_2O/acre to maximize yield potential, that accumulation of dry matter and K by hybrid rice was greater than for a conventional cultivar, that K fertilizer should be applied early and at a sufficient rate to maximize yield, and that mid- and late-season K fertilization can substantially increase yields of K-deficient rice.

INTRODUCTION

Research investigating rice response to various aspects of P and/or K fertilization is a continuous process needed to answer grower questions, develop soil-test based recommendations, or verify the accuracy of established recommendations. Research conducted during the past ten years has focused largely on correlating Mehlich-3 extractable P and K with rice yield response to fertilization, and calibrating fertilizer rates to soil nutrient availability index values. For K, we have found that soil-test K is a good index of soil K availability, that late-season K fertilization can increase yield of K deficient rice, and that soil K can be depleted quite rapidly across time when annual K fertilizer rates are inadequate. For P, we have established that the Mehlich-3 soil-test is a poor indicator of soil P availability for rice, that yield responses are maximized by P fertilizer applied from preplant to the tillering stage, and that there is no significant difference among granular P fertilizer sources. These findings are important components of current recommendations and/or highlight the areas where further research is needed.

Crop production systems are dynamic in that soils differ among fields, the fertility status of soil can change across time, and crop management components like cultivar, irrigation, and pest management practices change and influence crop yield potential. These factors require that soil fertility research be performed continuously. Thus, our research program continues to examine how rice responds to fertilizer rates, sources, and application times while now attempting to answer other questions that may be of interest in developing comprehensive nutrient management strategies for rice. This report includes results from several P and K fertilization trials that have different objectives. The objectives covered in this report include rice response to i) annual K fertilizer rate in a long-term fertilization trial, ii) P fertilizer rate and source, and iii) K fertilizer rate and application time. Additionally, we compared a hybrid and conventional cultivar response to K fertilizer rate.

PROCEDURES

Trials were established at the Pine Tree Research Station (PTRS) on a Calhoun silt loam, Lake Hogue Research Farm (LHRF) on a Hillemann silt loam, and a grower field in Prairie County on a Dewitt silt loam. Selected site characteristics for each trial are listed in Table 1. For each trial, before fertilizer treatments were applied, a composite soil sample (0- to 4-in. depth) was collected from each unfertilized control plot to determine soil chemical properties. Soil samples were dried at 50 °C in a forced-draft oven, crushed, and analyzed for soil water pH 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 spectroscopy. Selected soil chemical properties for each experiment are listed in Table 2. Soybean was the previous crop grown at all sites.

A long-grain cultivar (Table 1) was drill-seeded into a conventionally tilled or stale seedbed at all sites, except the annual K rate trial at PTRS which was no-till. 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 was 6.5-ft wide (7 to 9 rows of rice per plot) and 16-ft long with a 1- to 2.5-ft wide alley surrounding each plot. Specific information on each trial is listed in the following sections and Table 1.

P Source Trials

Triple superphosphate (TSP) and diammonium phosphate (DAP) fertilizers were each applied at 0, 30, 60, and 90 lb P_2O_5/acre before seeding at the PTBS or shortly after emergence at the LHRF. Muriate of potash (90 lb K_2O/acre) and zinc sulfate (10 lb Zn/acre) were broadcast to each research area the same day that P treatments were applied. Plots receiving TSP received no additional N to account for the N applied with each DAP rate. At the 5-lf stage, 130 lb N/acre as urea was broadcast to a dry soil and the permanent flood was established within 2 days. At the midtillering stage, whole, aboveground rice plants fertilized with 0 and 60 lb P_2O_5 rates were harvested from a 3-ft section of an inside row for dry matter determination. Samples were dried in a forced draft oven to a constant weight, weighed, ground to pass a 2-mm sieve, and digested with concentrated HNO_3 and H_2O_2 to determine tissue P concentration. Grain yield was determined by harvesting a 12-ft long section of the middle four rows at PTBS or all seven rows at LHRF. Grain yields were adjusted to a uniform moisture content of 12% for statistical analysis. Each experiment was a randomized complete block (RCB) design with a 2 (P source) by 3 (P rate) factorial treatment structure compared to a no P control. Each treatment was replicated four times per site. The factorial treatment structure was used for grain yield analysis of variance, but tissue P and dry matter were analyzed as an RCB since only selected treatments were sampled. Analysis of variance was performed with the GLM statement in SAS v9.2 with significant differences interpreted when $P < 0.10$. Locations were analyzed separately. Mean separations were performed by Fisher's Protected Least Significant Difference method.

Long-Term K Trial

A long-term K fertilization area at the PTRS was cropped to rice in 2009. The area was first established in 2001 and designated plots have received annual applications of the same K fertilizer rate each year. Only data from 2009 are reported here using a RCB design of annual K rates that were replicated nine times. Previous reports have summarized data from this area as two separate trials (PTBS-39 and -40, Slaton et al., 2008), but data were pooled for this report. Soil samples were collected from every plot in January 2009 and samples were processed as described previously.

Muriate of potash was applied at the established annual rates of 0, 40, 80, 120, and 160 lb K_2O/acre before planting in April 2009. Triple superphosphate (50 lb P_2O_5/acre) was broadcast to the research area before seeding. Rice emergence was non-uniform and occurred for about 30 days after planting, but the final seedling density among plots was uniform. At the 5-lf stage, 130 lb N/acre as urea was broadcast to a dry soil and the permanent flood was established within 2 days. The flood was removed the following week due to Zn deficiency. Zinc (1 lb Zn/acre) was foliar applied and an additional 46 lb N/acre was broadcast to a dry soil after rice started to recover (about 2 weeks) and the flood was reestablished. Due to uneven growth caused by the Zn deficiency, only grain yield, adjusted to 12% moisture, was measured. Analysis of variance was performed with the GLM statement in SAS v9.2 with significant differences interpreted when $P < 0.10$. Mean separations were performed by Fisher's Protected Least Significant Difference method.

Cultivar by K Rate Trial

Potassium uptake and grain yield of a hybrid (RiceTec CL XL745) and a conventional cultivar ('Francis') as affected by K fertilizer rate were compared in an experiment at the PTRS (Table 1). Triple superphosphate (50 lb P_2O_5/acre) and zinc sulfate (10 lb Zn/acre) were broadcast to the research area before planting. The seeding rates were 35 lb/acre for the hybrid and 90 lb/acre for Francis. Each plant type was fertilized with 0, 45, 90, and 135 lb K_2O/acre as muriate of potash on 20 May, 130 lb N/acre as urea was broadcast onto a dry soil on 2 June, and the permanent flood was applied on 4 June. At the early heading stage (29 July), whole plant samples were collected, processed, and analyzed as described for the P source trials. The trial was a RCB design with a 2 (plant type) by 4 (K rate) factorial treatment structure. Each treatment was replicated four times. Statistical analysis was performed as described previously.

K Rate and Application Time Trial

This trial was a continuation of the research reported by Slaton et al. (2009) regarding in-season management of K deficient rice. The trial was located in a Prairie County rice field (Table 1) having low soil test K (Table 2). Diammonium phosphate (50 lb P_2O_5/acre) and zinc sulfate (10 lb Zn/acre) were broadcast to the area after emergence. Muriate of potash was applied at the 5-lf (preflood, 9 June), panicle differentiation (midseason, 21 July), or late boot (13 August) stages at 0, 60, and 120 lb K_2O/acre. Nitrogen fertilization was performed by the cooperating rice producer. Plant samples were collected the same day the midseason K application was made from rice receiving 0, 60, and 120 lb K_2O/acre preflood and from all plots one week after the late boot K application was made. Plant samples and grain yield were collected, processed, and analyzed as described previously. Analysis of plant samples collected after the late boot stage are not yet complete.

The experiment was a RCB with a 2 (K rate) × 3 (application time) factorial treatment structure compared to a no K control. Each treatment was replicated eight times. Dry matter and nutrient uptake data from the midseason sampling were analyzed as an RCB since only one application (preflood) of each K rate had been made. Statistical analysis was performed as described previously.

RESULTS AND DISCUSSION

P Source Trials

Soil test P was *very low* at the LHRF and *medium* at the PTRS (Table 2) suggesting that rice grown at the LHRF was more likely to respond to P fertilization. However, the pH at LHRF was 6.3 compared to 8.0 at PTRS. Previous research has noted that rice seldom responds positively to P fertilization on soils with pH $\leq$ 6.5. Current P fertilization guidelines, based on soil pH and soil-test P, would have recommended a maintenance application of 50 lb P_2O_5/acre at each site.

Dry matter accumulation of rice receiving 0 and 60 lb P_2O_5/acre was not significantly affected at either site (Table 3, only rate means are shown). Tissue P concentration of rice at PTRS was similar for rice receiving no P and 60 lb P_2O_5/acre as DAP and TSP; but at LHRF, rice receiving P had a greater tissue P concentration than rice receiving no P. Tissue P concentrations of rice receiving no P at both sites would be considered low, but not deficient. Grain yield was not affected by P source, P rate, or their interaction at either site.

Long-Term K Trial

Zinc deficiency, believed to be caused by uneven seeding depth, resulted in a great deal of growth and yield variation in this trial. However, the large number of replications ($n = 9$) and a highly significant effect of annual K rate make the data worthy of reporting. The areas of Zn-deficient rice corresponded with areas of deep seed placement caused by variable residue cover and soil moisture at the time of planting. Zinc fertilizer has been applied to this research site consistently during the past 10 years and has resulted in an optimal soil-test Zn value. However, the majority of the Zn is likely in the top inch of soil because tillage is seldom performed to maintain the integrity of the plot (i.e., K rate) boundaries. Thus, we believe that the roots of seedlings originating from deep-placed seed were growing below soil that was enriched with Zn, an immobile element. Overall, yield potential was reduced by Zn deficiency in this trial, as compared to other nearby trials that were seeded on the same date.

Annual K rate had a very significant effect on soil-test K and grain yield in 2009 (Table 4). Soil-test K in the 0- to 4-in. depth has changed across time due to annual K rate with numerical soil-test K increasing as annual K rate increased. In 2009, soil receiving annual K applications ≤80 lb K_2O/acre/year had a *low* soil-test K level and soil fertilized with 120 and 160 K_2O/acre/year had a *medium* soil-test K level. Rice yield reflected the annual K fertilizer rate with maximum yields produced by rice receiving ≥80 lb K_2O/acre/year. For rice receiving <80 lb K_2O/acre/year, yields decreased incrementally as annual K rate decreased. For this soil, application of >40 lb K_2O/acre/year is needed to maintain adequate soil K fertility to maximize rice yield potential.

Cultivar by K Rate Trial

Soil had an *optimum* soil-test K level (Table 2) suggesting that no positive yield response to K fertilization would be measured. The plant type by K rate interaction was not significant for dry matter accumulation ($P = 0.1625$), tissue K concentration ($P = 0.6523$), K uptake ($P = 0.5065$), or grain yield ($P = 0.7906$). Only the main effects of K rate or plant type had significant effects on the measured growth parameters (Table 5). Dry matter and K concentration at early heading were similar among K rates, but tissue K concentration increased numerically as K rate increased. Grain yield was similar for rice fertilized with 0 to 90 lb K_2O/acre, but decreased when the rate was increased to 135 lb K_2O/acre. Although the reason for the yield decrease is unclear, it was consistent for both plant types. Dry matter accumulation, K uptake, and grain yield were about 20% greater for the hybrid compared to Francis. However, despite the difference in dry matter between plant types, tissue K concentration was nearly identical.

K Rate and Application Time Trial

The soil at the Prairie County site had a *low* soil-test K level (Table 1) suggesting that a large and positive rice yield response to K fertilization would occur. At midseason, rice receiving preflood K had greater tissue K concentrations, K uptake, and dry matter accumulation than rice receiving no K (Table 6). Approximately 44% of the K fertilizer applied preflood was recovered in the aboveground portion of plants by midseason. Despite the growth differences from K fertilization, rice exhibited no obvious K deficiency symptoms. By one week after the final (late boot) K application, rice dry matter continued to show a significant increase from K fertilization, but still showed only subtle K deficiency symptoms. Grain yields were increased by 24% to 35% from application of 60 to 120 lb K_2O/acre, averaged across K application times. These data suggest that K deficiency has a greater influence on rice grain yield than dry matter production, as the maximum dry matter increases from K fertilization were 9% and 14% at heading and midseason, respectively.

Time of K fertilization, averaged across K rates, had no influence on dry matter at early heading ($P = 0.5444$), but significantly influenced rice yield ($P < 0.0001$)(Table 6). Rice yields were greatest for K applied preflood (175 bu/acre, LSD.10 = 7 bu/acre) and least for rice that received no K (126 bu/acre). Fertilization at midseason (148 bu/acre) and the late boot (165 bu/acre) stage both increased yields compared to the no K control, but had yields lower than when K was applied preflood. The yields from midseason and late boot K applications were unexpected and different than results reported in 2008 (Slaton et al., 2009), but consistent throughout the test. Specific reasons why the yield of rice receiving the midseason K application were lower than rice that received K at late boot are unknown. The only explanation we can propose is that significant rainfall (1.5 to 2.5 in.) occurred within hours after the midseason K was applied into the floodwater. Water flow through the field may have resulted in movement of the dissolved K into other plots and the surrounding field, which would have diluted the K available for plant uptake in the midseason designated plots and perhaps increased K uptake in other treatments. The preflood K was applied to a dry soil and the late boot K was applied into the flood (no rain for 6 days afterwards). Plant K uptake from the early heading stage should be helpful in determining whether K uptake occurred or another unknown factor was responsible for the yield results. We have previously measured significant amounts of K fertilizer applied to a dry soil immediately before flooding in field floodwater (unpublished data). Regardless, the results show that K is best applied before tillering occurs and that significant yield increases can be realized from mid- and late-season K applications.

SIGNIFICANCE OF FINDINGS

Results of these trials add to the overall databases describing rice growth, nutrient uptake, and yield response to P and K fertilization and should be of use for developing and/or refining soil-test based fertilizer recommendations for P and K. The most significant findings from these trials include: i) that there is little or no difference in P availability between TSP and DAP, ii) that soils with *low* to *medium* soil-test K values required annual K rates >40 lb K_2O/acre to maximize yield potential, iii) that accumulation of dry matter and K by a hybrid rice was greater than for a conventional cultivar, but tissue concentrations were very similar, and iv) that K fertilizer should be applied early and at a sufficient rate to maximize yield, but mid- and late-season K fertilization can increase yields of K-deficient rice. The tissue concentrations that are considered low and deficient for conventional cultivars may also be diagnostic for hybrid rice. Additional research on K-deficient soils is needed to determine whether hybrid and conventional rice respond similarly to K fertilization.

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Table 1. Agronomic and field information for field sites used to evaluate rice response to P and K fertilization on silt loam soils during 2009.

Site[z]	Test objective	Cultivar	Soil series	Plant date
				(day - month)
LHRF	P source	Wells	Hillemann	19 May
PTRS	P source	Wells	Calhoun	22 April
PTRS	Cultivar x K rate	Francis and CLXL745	Calhoun	22 April
PTRS	Annual K rate	Wells	Calhoun	24 April
Prairie	K rate and time	Wells	Dewitt	21 May

[z] LHRF = Lake Hogue Research Farm; PTRS = Pine Tree Research Station; and Prairie = a commercial rice field in Prairie County.

Table 2. Selected soil chemical characteristics (0- to 4-in. depth) of sites used to evaluate rice response to P and K fertilization on silt loam soils in 2009. Values in () are the standard deviation of the mean.

Field	Soil[y]		Mehlich-3 extractable soil nutrient concentrations[x,w]							
name[z]	OM	pH	P	K	Ca	Mg	S	Fe	Mn	Zn
	(%)		----------(ppm)----------							
P source										
LHRF	2.8	6.3	13 (4)	107	1079	221	12	329	242	2.7
PTRS	2.0	8.0	27 (2)	93	1669	326	5	337	151	1.5
Potassium trials										
PTRS-LT	3.0	8.0	26	66 (11)	2200	383	14	368	245	7.2
PTRS-CK	1.7	7.9	33	146 (10)	1733	432	8	219	303	1.5
Prairie	2.7	5.7	3	62 (3)	1227	178	10	358	177	0.7

[z] LHRF = Lake Hogue Research Farm; PTRS = Pine Tree Research Station; LT = long term K trial; CK = cultivar by K rate trial; and Prairie = a commercial rice field in Prairie County.

[y] OM, organic matter by weight loss on ignition. Soil pH measured in a 1:2 soil:water mixture.

[x] Mehlich-3 extraction procedure (1:10 extraction ratio).

[w] All values are the mean of four or more composite samples taken from the 0- to 4-in. depth.

Table 3. Tissue P concentration and dry matter accumulation means at the midtillering stage and grain yield of rice as affected by P rate, averaged across P sources, at the Pine Tree Research Station (PTRS) and Lake Hogue Research Farm (LHRF) in 2009.

	PTRS			LHRF		
P rate	Dry matter	Tissue P	Grain yield	Dry matter	Tissue P	Grain yield
(lb P_2O_5/acre)	(lb/acre)	(%)	(bu/acre)	(lb/acre)	(%)	(bu/acre)
0	991	0.21	157	1601	0.18	226
30	--	--	150	--	--	224
60	963	0.22	160	1806	0.29	227
90	--	--	158	--	--	217
LSD0.10	--	--	NS	--	--	NS
P-value	--	--	0.2043	--	--	0.2066

Table 4. Soil-test K and rice yield response to annual K rate for a long-term trial conducted at the Pine Tree Research Station.

Annual K rate	Soil-test K	Grain yield
(lb K_2O/acre/year)	(ppm)	(bu/acre)
0	66	92
40	79	122
80	86	136
120	109	134
160	116	145
LSD0.10	13	11
P-value	<0.0001	<0.0001

Table 5. Rice dry matter, whole-plant K concentration, and K uptake at early heading and grain yield as affected by K rate, averaged across plant types (conventional or hybrid), or plant type, averaged across K rate.

K rate	Dry matter	K concentration	K uptake	Grain yield
(lb K_2O/acre)	(lb/acre)	(% K)	(lb K/acre)	(bu/acre)
0	14,723	1.74	257	204
45	15,688	1.80	282	208
90	14,409	1.84	265	205
135	16,119	1.86	299	190
LSD0.10	NS	NS	33	13
p-value	0.1384	0.1832	0.0930	0.0986
Cultivar				
Francis	13,869	1.81	251	182
CLXL745	16,605	1.81	301	221
LSD0.10	1117	NS	23	9
p-value	0.0003	0.9489	0.0930	0.0001

Table 6. Dry matter accumulation at midseason and early heading, midseason tissue K, and grain yield of rice as affected by K application rate, averaged across application times, for a trial conducted in a Prairie County rice field during 2009.

	Midseason			Heading	
K rate	Dry matter	Tissue K	K uptake	dry matter	Grain yield
(lb K_2O/acre)	(lb/acre)	(% K)	(lb K/acre)	(lb/acre)	(bu/acre)
0	3188	0.96	31	8201	126
60	3415	1.55	53	8481	156
120	3641	2.07	75	8958	170
LSD0.10	298	0.14	8	445	6
P-value	0.0554	<0.0001	<0.0001	0.0762	0.0003

RICE CULTURE

Rice Response to Urea and Two Polymer-Coated Urea Fertilizers

N.A. Slaton, B.R. Golden, and R.J. Norman

ABSTRACT

The availability and affordability of a nitrogen (N) source that can be preplant incorporated and recovered efficiently by rice would have numerous agronomic, economic, and environmental advantages for rice management compared with the standard fertilization practices currently in use. This report describes rice response to two experimental polymer-coated urea (PCU) fertilizers applied preplant and at the 2- to 3-lf stage compared to urea applied at the 2- to 3-lf stage and preflood. Research was established on two silt loam sites and one clay soil site with each experiment containing a total of 13 treatments including a no N control and three N sources each applied at 60 and 120 lb N/acre at two different times. The three N sources included 1) urea, 2) a 38% N PCU, and 3) a 43% N PCU. The PCU fertilizers were applied preplant and at the 2- to 3-lf stage of rice. Rice receiving the 38% N PCU preplant produced similar to slightly lower grain yields as urea applied preflood on the silt loams. On the clay soil, urea applied preflood produced the greatest yield; but for the 2- to 3-lf application, the 38% PCU produced greater yield than urea applied at the same time. The 43% N PCU released N too rapidly and tended to produce inferior rice yields. The 38% PCU shows some promise for use as an alternative N source for rice production, but requires additional research and refinement.

INTRODUCTION

The availability and affordability of an N source that can be preplant incorporated and recovered efficiently by rice would have numerous agronomic, economic, and environmental advantages for rice management compared with the standard fertilization practices currently in use. Rice usually receives the majority of its N as urea applied preflood by airplane. Efficient use of the fertilizer N requires that urea be applied to a dry soil and flooded as quickly as possible to reduce N losses from ammonia volatilization and nitrification/denitrification. Many fields require 7 to 14 days to establish a flood due to inadequate pumping capacity and/or when hot, dry weather conditions persist. In some years, wet soil conditions from frequent rainfall may delay the preflood N application resulting in reduced yield and increased N rates to compensate for N loss. Fertilizer N use efficiency is known to differ among soils with soil pH being one of the most important factors. Soils with high pH have a greater potential for ammonia volatilization and tend to have more rapid nitrification rates than soils with a slightly acidic pH.

Polymer coatings and inhibitors (chemicals that inhibit urease activity or nitrifying microorganisms) that can be applied to urea have potential for reducing N losses attributed to ammonia volatilization and nitrification. The cost of PCU has generally prohibited their use in large-scale production agriculture systems. However, emphasis on reducing greenhouse gas emissions and inorganic N losses has lead to the development and marketing of PCU for corn production in the midwestern U.S. and stimulated interest in its use for rice production. During the past several years, we have evaluated several PCU fertilizers and provided input to the fertilizer industry on the N-release pattern that is needed for rice grown in the direct-seeded, delayed flood management system. This report describes rice response to two experimental PCU fertilizers applied preplant and at the 2- to 3-lf stage compared urea applied at the 2- to 3-lf stage and preflood.

PROCEDURES

Three field trials evaluating three N sources were established in 2009. Field sites included a Calhoun silt loam at the Pine Tree Research Station, a Dewitt silt loam at the Rice Research Extension Center, and a Sharkey clay at the Southeast Branch Station. Soybean was grown in 2008 on the Dewitt and Sharkey soils, while the Calhoun site was fallowed in 2008. The Calhoun and Sharkey soils receive irrigation water from a well, whereas reservoir water is the irrigation source for the Dewitt soil. Composite soil samples (n = 3-8) were collected from each research area before planting, oven-dried, crushed to pass a 2-mm sieve, and analyzed for soil pH (1:2 soil water mixture), total C and N, and Mehlich-3 extractable soil nutrients (Table 1).

'Wells' rice was drill-seeded (6.0- to 7.5-in. drill spacing) on 22 April for the Calhoun soil, 23 April for the Sharkey soil, and 29 April for the Dewitt soil. Seeding rates were 100 lb seed/acre for the silt loam soils and 120 lb seed/acre for the Sharkey clay. Rice emerged uniformly and to an adequate stand at each silt loam site, but emergence was non-uniform on the clay soil. Wet soil conditions prohibited replanting on the clay soil. Therefore, research was initiated on the clay soil with the existing population of rice. Before seeding, each site received a blanket application of 40 lb P_2O_5/acre as triple super phosphate. The two silt loam soils also received 60 lb K_2O/acre as muriate of potash and the Calhoun soil received 15 lb Zn/acre as a 35.5% Zn granular fertilizer. Pest control was performed as needed.

The experiment contained a total of 13 treatments including a no-N control and three N sources each applied at 60 and 120 lb N/acre at two different times. The three N sources included 1) urea, 2) a 38% N PCU, and 3) a 43% N PCU. Agrium provided two PCU fertilizers and urea was obtained from a local supplier. The PCU fertilizers were applied preplant and at the 2- to 3-lf stage of rice. Urea was applied at the 2- to 3-lf stage and preflood. The preplant N treatments were applied 22 April for the Calhoun soil, 23 April for the Sharkey soil, and 29 April for the Dewitt soil. The 2- to 3-lf stage N was applied 20 May for the Calhoun soil, 21 May for the Sharkey soil, and 30 May for the Dewitt soil. The preflood urea was applied 1 or 2 days before flooding (DBF) at each site, which corresponded to 2 June on the Calhoun and Sharkey soils and 9 June on the Dewitt soil. The 2- to 3-lf stage N applications were made 15 DBF on the Calhoun soil, 14 DBF on the Sharkey soil, and 12 DBF on the Dewitt soil. At both silt loam sites, >1 in. of rain occurred 4 days after the 14 DBF N was applied. A total of 1.3 in. of rain occurred on the Dewitt soil on 4 June, 1.3 in. on the Sharkey soil on 24 May, and 2.4 in. on the Calhoun soil with the majority of rain on 24 (1.15 in.) and 26 (1.18 in.) May.

Grain yield was measured at maturity by harvesting the entire plot (Dewitt and Sharkey soils) or the middle four rows in each plot with a small-plot combine (Calhoun). The weight and moisture content of grain harvested from each plot were measured immediately following harvest. Grain moisture content was adjusted to 12% for statistical analysis.

Each field trial was a randomized complete block design with a 2 (N rate) × 3 (N source) 2 (N application time) factorial treatment structure. The factor of N time included the 2- to 3-lf stage application for all N sources and a second application time considered as the standard for each fertilizer (preplant for PCU or preflood for urea). Data from rice receiving no N was not included in the statistical analysis, but is listed in data tables for reference. Treatments were replicated five times at each silt loam site and four times at the clay soil site. Analysis of variance was performed using the PROC GLM statement in SAS v9.1. Data from each site were analyzed separately. When appropriate, mean separations were performed by Fisher's Protected Least Significant Difference method at a significance level of 0.10.

RESULTS AND DISCUSSION

For rice grown on the Sharkey clay soil, rice stand density was non-uniform among plots, but grain was harvested for yield and statistically analyzed. The coefficient of variation for the grain yield on the Sharkey clay soil was comparable (10.8%) to the C.V. for rice grown in the Calhoun soil (12.3%) and higher than that for the Dewitt soil (5.0%), but required that three plots be omitted from the analysis (C.V. with all data on the Sharkey clay was 14.5%). Thus, we advise that caution be used when reviewing the yield results from the Sharkey clay

The N source × N rate × application time interaction significantly affected rice grain yield on the Sharkey clay (Table 2). Rice grown on the Sharkey clay and receiving no N yielded 57 bu/acre (Table 3). The greatest yield was produced by 120 lb urea-N/acre applied preflood. The lowest overall yields were produced by rice receiving 60 lb urea-N/acre at the 2-lf stage and 60 and 120 lb N/acre as 43% N PCU applied preplant. The greatest yield difference (and the greatest overall yields) between N rates was for urea applied preflood (45 bu/acre), while yields between N rates of all other N sources and application times differed by 9 to 34 bu/acre suggesting that total N loss increased as N rate increased. Within each N rate, yields of rice receiving the 43% N PCU increased when fertilizer application was delayed until the 2- to 3-lf stage indicating this PCU fertilizer released its N too rapidly. Yield results also indicate that the 38% N PCU released its N too rapidly since yields within each N rate were always greater for N applied at the 2- to 3-lf stage. However, the second greatest yield among all treatments was produced with 120 lb N/acre as the 38% N PCU applied at the 2- to 3-lf stage. Urea (46%, no polymer) was the least effective fertilizer applied at the 2- to 3-lf stage. Overall, these data suggest that only the 38% PCU fertilizer may offer some potential as a post-emergence N fertilizer alternative to urea applied preflood.

The primary concern with applying any PCU fertilizer post-emergence is the potential for physical movement of the fertilizer granules within the field resulting in non-uniform N distribution and perhaps out of the field should sufficient rainfall occur to cause significant runoff or irrigation levees to fail. The Sharkey, and other clayey, soils used for rice production in Arkansas are Vertisols. The shrink-swell potential of these soils causes the crusted soil surface to ‘crack open’ during drying following rainfall or irrigation flushes. The cracks are large enough that fertilizer granules may lodge in the cracks and prevent significant granule movement. Although a PCU fertilizer clearly has potential as a post-emergence N source on such soils, fertilizer application via ground equipment is not always feasible if levees have been constructed.

Although the 3-way interaction had no significant effect (Table 2) on grain yield for either silt loam soil, the mean yields for each treatment are listed in Table 3. For the Dewitt soil, the main effect of N rate and the N source × application time interaction significantly affected grain yield (Table 2). Rice receiving no N fertilizer yielded 138 bu/acre indicating a high level of native soil N availability (Table 3). Rice yield, averaged across N sources and application times, was greater for rice fertilized with 120 lb N/acre (182 bu/acre, LSD 0.10 = 4) than 60 lb N/acre (165 bu/acre). The significant 2-way interaction, averaged across N rates, showed that rice fertilized with the urea and 43% N PCU sources produced equal yields between the standard application time (preflood and preplant, respectively) and the 2- to 3-lf stage application. Only the 38% N PCU produced different yields between application times with the preplant application having greater yields. A comparison of N sources within each application time showed that urea produced greater yields than either N PCU fertilizer. This result may have been due to physical movement of the PCU following rainfall events into the no plant area between plots following the 2- to 3-lf stage application. Furthermore, some N loss would be expected from N released from the preplant applied PCU fertilizer followed by nitrification and denitrification when the soil became saturated. Preplant application of the 38% N PCU fertilizer produced yields closest to that of urea applied preflood. Although the nitrification rate of the Dewitt soil is much slower than that of the Calhoun (Golden et al., 2009), some N loss of NO_3-N via denitrification would be expected.

Grain yield of rice grown on the alkaline Calhoun silt loam was affected by significant 2-way interactions between N source and N rate and N source and N application time (Table 2). Rice receiving no N produced an average yield of 41 bu/acre, which is typical for this site as this soil has a low amount of mineralizable soil N and a rapid nitrification rate (Table 3). These soil traits make this site the most difficult situation for N fertilization of rice and is likely typical of most silt loam soils used for rice production. Season total N rates >150 lb N/acre are usually needed to maximize yields on this soil. The lowest rice yields, averaged across N rates, were produced by rice fertilized with urea at the 2- to 3-lf stage and 43% PCU applied at the 2- to 3-lf stage and preplant. Rice yields were greatest numerically from rice fertilized with urea applied preflood, which produced a statistically similar yield to rice fertilized with 38% N PCU preplant. Although PCU granules applied postemergence did not move as much on the Calhoun soil as compared to the Dewitt soil (due to planting method), some granule movement to plot boundaries and alleyways still occurred and may have affected the 2- to 3-lf stage application yields. Within each fertilizer source, rice yields were numerically and sometimes significantly lower for N applied at the 2- to 3-lf stage compared to the standard application time for each fertilizer; the 43% N PCU fertilizer was the exception to this generalization. Averaged across N application times, 120 lb N/acre applied as 38% N PCU or urea had the greatest grain yields that were greater than rice fertilized with the 43% N PCU (Table 4). For the 60 lb N/acre rate, the rank of N sources was 38% N PCU > urea > 43% N PCU. Within each N source, rice yield was always greater for rice receiving 120 lb N/acre, but the magnitude differed among N sources. Although the 38% N PCU compared favorably to urea in the significant 2-way interactions, the mean yields in Table 3 show that urea applied preflood at 120 lb N/acre produced the greatest numerical grain yields of all treatments.

SIGNIFICANCE OF FINDINGS

Yield results from three research sites established in 2009 indicate that the 43% N PCU is not an acceptable alternative N source to urea applied preflood, regardless of N application time. The 38% N PCU fertilizer produced yields that were comparable, albeit slightly lower (when all three sites are considered), to urea applied preflood and shows promise as a fertilizer that could potentially be used in the direct-seeded, delayed-flood rice production system. The 38% N PCU should be included in further lab and field trial evaluations to establish whether the responses observed in 2009 are consistent, especially on the Calhoun soil. These results are encouraging, but require that the 38% N PCU fertilizer be evaluated across a suite of N rates to compare grain yield by N response curves with urea applied preflood. Mean yields (for each treatment) from the PTRS and RREC both indicate that urea was slightly better than the 38% N PCU at the N rates needed to maximize grain yield.

We believe that the ideal PCU fertilizer for our rice production system is one that would release little to no N for approximately 45 days after soil application followed by a rapid release of N for the next 3 or 4 weeks (66 to 75 days after application). This would allow the PCU fertilizer to be mechanically incorporated before seeding. The only problems we can foresee with such an N-release mechanism of this time distribution is that it may not work for late-planted rice, which may emerge and be ready for flooding in 30 or 35 days due to warmer temperatures, or result in the need for supplemental N if a field needs to be replanted.

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Table 1. Selected soil properties of field sites used in fertilizer evaluations conducted in 2009.

	Soil	Total	Mehlich-3 extractable soil nutrients								
Soil	pH	C	P	K	Ca	Mg	Na	S	Mn	Cu	Zn
		(%)	(ppm)								
Dewitt	5.7	0.85	29	134	979	181	60	9	149	1.3	6.1
Calhoun	8.3	0.80	34	82	2110	404	40	8	209	1.8	1.9
Sharkey	8.2	1.34	63	317	4338	852	136	13	89	1.3	3.8

Table 2. Analysis of variance P values for rice grain yield for three field trials conducted in Arkansas during 2009. Notes: the no-N control was not included in statistical analysis and the application times for urea (preflood) and PCU (preplant) were listed as 'Standard' for the fertilizer.

	Grain yield (by Soil)		
Source of variation	Calhoun	Dewitt	Sharkey
Rep	<0.0001	<0.0001	0.5002
N source (NS)	<0.0001	<0.0001	<0.0001
N rate (NR)	<0.0001	<0.0001	<0.0001
N time (NT)	<0.0001	0.0163	0.5388
NS × NR	0.0376	0.6762	0.3829
NS × NT	0.0001	0.0011	<0.0001
NR × NT	0.9888	0.4336	0.3885
NR × NS × NT	0.1627	0.1224	0.0378

Table 3. Rice grain yield as affected by N source, N rate, and application time (DBF, days before flooding) for rice grown on a Calhoun silt loam, Dewitt silt loam, and Sharkey clay during 2009.

N source (Soil)	Application time	Mean	N rate (lb N/acre) 60 lb N/acre	120 lb N/acre
	(DBF)	(across N rates)	----------- Yield (bu/acre)	------------
Calhoun				
No N (reference)		41	41	
38% N (PCU)[z]	Preplant	114	104	125
43% N (PCU)	Preplant	79	68	90
Urea	Preflood	121	103	140
38% N (PCU)	2-3 lf	106	88	124
43% N (PCU)	2-3 lf	80	75	85
Urea	2-3 lf	87	70	104
P-value		0.0001	0.1627	
LSD0.10		9	NS	
		Mean	60 lb N/acre	120 lb N/acre
		(across N rates)	----------- Yield (bu/acre)	------------
Dewitt				
No N (reference)		138	138	
38% N (PCU)	Preplant	179	168	189
43% N (PCU)	Preplant	161	155	168
Urea	Preflood	189	183	194
38% N (PCU)	2-3 lf	161	155	167
43% N (PCU)	2-3 lf	165	152	178
Urea	2-3 lf	186	176	195
P-value		0.0011	0.1224	
LSD0.10		7	NS	
		Mean	60 lb N/acre	120 lb N/acre
		(across N rates)	----------- Yield (bu/acre)	------------
Sharkey				
No N (reference)		57	57	
38% N (PCU)	Preplant	113	105	119
43% N (PCU)	Preplant	76	71	80
Urea	Preflood	178	156	201
38% N (PCU)	2-3 lf	152	137	168
43% N (PCU)	2-3 lf	120	101	135
Urea	2-3 lf	89	78	100
P-value		<0.0001	0.0378	
LSD0.10		12	16	

[z] PCU = polymer-coated urea.

Table 4. Rice grain yield means, averaged across N application times, as affected by the N source × N rate interaction for rice grown on the Calhoun silt loam in 2009.

	N rate (lb N/acre)	
N source	60 lb N/acre	120 lb N/acre
	------------------ Yield (bu/acre)-------------------	
No N (reference)	41	
38% N (PCU)	97	124
43% N (PCU)	71	87
Urea	86	122
P-value	0.0376	
LSD0.10	9	

Rice Kernel Chalkiness and Milling Quality Relationship of Selected Cultivars

R.C. Bautista, T.J. Siebenmorgen, and P.A. Counce

ABSTRACT

This study quantified the level of chalkiness and the correlation to head rice yield (HRY) of two medium-grain cultivars, 'Bengal' and 'Jupiter', and four long-grain cultivars, 'Cypress', 'LaGrue', 'Wells', and 'XL723', that were hand-harvested over a range of moisture contents (MCs) from five locations in Arkansas in 2007 and 2008. Growing location and year significantly affected kernel chalkiness level. Among cultivars, Bengal, Cypress, and Jupiter were least susceptible, Wells was moderately resistant, and LaGrue and XL723 were highly susceptible to chalk formation. Cultivar susceptibility to chalk formation was attributed to the cultivar's inherent genetic response to various environments during kernel formation. Kernel chalkiness was inversely and linearly correlated to HRY.

INTRODUCTION

Chalkiness in rice kernels is an undesirable characteristic because it degrades the visual appearance and cooking quality of milled rice. Head rice yield, defined as the mass percentage of rough rice that remains as head rice (milled kernels that are at least three-fourths of the original kernel length after complete milling, USDA, 2005), is the most commonly used indicator of rice milling quality. Chalkiness generally lowers HRY as chalky kernels tend to be weaker and are more prone to breaking during milling than non-chalky, fully translucent kernels (Webb, 1991; Siebenmorgen and Qin, 2005).

Rice kernel chalkiness has been reported to be influenced by both cultivar genetics and the production environment (Mackill et al., 1996; Yamakawa et al., 2007). Long-grain Cypress and medium-grain Bengal have been cited to be resistant to chalkiness and have good milling qualities (Linscombe et al., 1991; Cooper et al., 2008). Environmental factors that influence kernel chalkiness include high temperatures during certain stages of kernel development (Cooper et al., 2008; Tashiro and Wardlaw, 1991) and infection by rice blast and sheath blight (Candole et al., 2000). Cooper et al. (2008) conducted a controlled temperature study testing nighttime temperature levels of 18, 22, 26, and 30 °C from 12 am until 5 am during the R6 growth stage (Counce et al., 2000) on physicochemical properties of long-grain cultivars Cypress, LaGrue, XP710, XL8, and medium-grain cultivars M204 and Bengal. The number of chalky kernels increased with an increase in nighttime temperature for all cultivars except Bengal and Cypress. In turn, as nighttime temperature was increased, head rice yields decreased for cultivars LaGrue, M204, XL8, and XP710, but remained near constant for Bengal and Cypress. Cooper et al. (2008) indicated that high nighttime temperatures during kernel filling affected the percentage of chalky kernels and the level of chalk was strongly and inversely related to HRY.

It is important to quantify chalkiness in current cultivars across production environments, and because of its apparent tie to milling quality, correlate chalkiness levels to milling quality. This information could help in the development of cultivars that are resistant to kernel chalk formation and thus, improve milling and end-use quality. The objectives of this study were to firstly quantify the level of chalkiness in samples of selected rice cultivars harvested over a range of MCs from five locations in Arkansas in 2007 and 2008, and to secondly correlate the levels of chalkiness to HRY.

MATERIALS AND METHODS

Sample Collection and Preparation

Panicles of medium-grain rice cultivars, Bengal and Jupiter, long-grain cultivars, Cypress, LaGrue, and Wells, and a long-grain hybrid XL723 were hand-harvested at MCs ranging from 12% to 30%[1] from Corning, Newport, Stuttgart, and Rohwer, Ark., in 2007 and Corning, Pine Tree, Stuttgart, and Rohwer, Ark., in 2008. Table 1 summarizes the harvest moisture contents (HMCs) of samples. Each year/location/cultivar/replication/HMC lot comprised approximately 120 panicles, which yielded at least 600 g of rough rice after threshing and cleaning. Immediately after harvest, five panicles were randomly selected from each 120-panicle lot; kernels were stripped by hand from the panicles and the MCs of 300 of these kernels were measured using a single kernel moisture meter (CTR 800E, Shizuoka Seiki, Shizuoka, Japan). The average MC of the 300 kernels was used as the lot HMC. The remaining panicles from each lot were mechanically threshed in a portable thresher (SBT, Almaco, Nevada, Iowa). Rough rice was cleaned, and dried to 12.5% MC, and stored in sealed plastic bags at 4 °C until scanning and milling analyses.

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[1] All moisture contents have been expressed on a wet basis.

Kernel Chalkiness Measurements

Chalkiness was measured using an image analysis system (WinSeedle™ Pro 2005a Regent Instruments Inc., Sainte-Foy, Quebec, Canada). The system included a scanner (Epson Perfection V700 Photo, Model# J221A, Seiko Epson Corp., Japan) that captured kernel images, which were processed by discriminating chalky areas in the kernels against a background color. Prior to measurements, the imaging system was configured to color-classify chalky kernels by presenting a completely chalky brown rice kernel to the imaging system. The background color selected was royal blue. Chalkiness was quantified as the proportion of opaque relative to translucent areas of kernels. Percent kernel chalkiness was measured using the procedure below.

Rough rice (10 g) from each lot was dehulled using a manually-operated, portable dehuller (Rice Husker TR120, Kett Electric Laboratory, Tokyo, Japan). From each lot, two sets of 100 brown rice kernels were randomly selected for scanning. The 100 brown rice kernels were positioned on a tray (152 mm × 100 mm × 20 mm) made from a 2 mm-thick clear acrylic sheet (Plexiglass) such that no kernel was touching another kernel. The tray was then placed on the scanner for imaging. Percent chalkiness was measured as the percent of total projected area of 100 kernels. The chalk level for each lot was the average of two measurements of 100 kernels.

Milling Analyses

Rough rice lots were withdrawn from storage and allowed to equilibrate in plastic bags at room temperature for 24 h prior to milling analysis. Two, 150-g rough rice samples from each lot were dehulled using a laboratory huller (THU35A, Satake Engineering Co., Hiroshima, Japan). The resulting brown rice was milled using a laboratory mill (McGill No. 2, RAPSCO, Brookshire, Texas) for 30 s. A 1500-g mass was placed on the mill lever arm, 15 cm from the center of the milling chamber. Head rice was separated from brokens using a sizing machine (Grainman, Model 61-115-60, Grain Machinery Manufacturing Corp., Miami, Fla.) with screen size #10 (10/64 in.) for medium-grain and #12 (12/64 in.) for long-grain cultivars.

Surface lipid content (SLC) of head rice was measured using a lipid extraction system (Soxtec Avanti 2055, Foss North America, Eden Pairie, Minn.) following the methods of Matsler and Siebenmorgen (2005). Head rice yields were adjusted to account for varying SLCs based on the method of Cooper and Siebenmorgen (2006):

$$HRY_{adjusted} = HRY_{sample} - 8.5(SLC_{sample} - SLC_{standard}) \text{ (Eq. 1) for medium-grain cultivars, and}$$

$$HRY_{adjusted} = HRY_{sample} - 11.3(SLC_{sample} - SLC_{standard}) \text{ (Eq. 2) for long-grain cultivars;}$$

where $HRY_{adjusted}$ = the HRY of a rice lot, adjusted for differences in SLC between the sample SLC and a desired, specified SLC (%); HRY_{sample} = the HRY of a sample with a given degree of milling (SLCsample) (%); $SLC_{standard}$ = the predetermined, specified SLC of a standard or processing application (%). In this study, the chosen SLC standard was 0.4%.

For each year/location/cultivar, the peak HRY was determined as the maximum HRY for a rice lot set harvested at different HMCs by utilizing the first derivative of the quadratic equation relating HRY and HMC (Siebenmorgen et al., 2007). The adjusted peak HRY was then determined using Eq. 1 and Eq. 2 to account for varying SLCs. Data analyses were performed using JMP® (ver. 8.0, SAS, Cary, N.C.) for the analysis of variance, means comparison tests on chalkiness percentage, and correlations of chalk percentage to HRY.

RESULTS AND DISCUSSION

Production Location Effects on Chalkiness

Table 2 shows year, location, and cultivar effects on kernel chalkiness. In 2007, the mean percent chalkiness for each cultivar differed significantly ($P < 0.0001$) among locations. For Bengal, chalkiness was greatest at Rohwer followed by Corning, Stuttgart, and Newport. A similar trend was observed for Cypress, LaGrue, Wells, and XL723, indicating a strong location effect on kernel chalkiness. For Jupiter in 2007, the greatest chalkiness was observed at Corning with Rohwer, Stuttgart, and Newport having similar levels. Among locations, Newport had the least chalkiness among cultivars in 2007. These results indicated a strong location, and presumably an environmental, effect on cultivar response to chalkiness.

In 2008, location had a less dramatic effect on chalk percentage than in 2007 (Table 2). Neither Bengal nor Jupiter significantly differed in mean percent chalkiness across locations. Slight differences in chalk levels were evident among Cypress, LaGrue, Wells, and XL723 across locations. Among locations, Rohwer showed slightly greater kernel chalkiness for all long-grain cultivars. These results demonstrate location effects on kernel chalkiness, albeit to a smaller degree than 2007.

Variability in Kernel Chalkiness

The overall mean percent kernel chalkiness levels of the six cultivars, averaged across the five locations and HMCs indicated in Table 1, are shown in Fig. 1. Mean percent chalkiness of the six cultivars across HMC and location varied from 3.9 to 11.1% in 2007 and from 1.4 to 5.1% in 2008. In 2007, chalkiness did not differ among Bengal, Jupiter, and Cypress. This result corroborates the findings of Linscombe et al. (1991) wherein Bengal and Cypress were found to have low incidence of kernel chalkiness. Siebenmorgen and Qin (2005) also showed Cypress to have low incidence of chalky kernels. In 2007, long-grains LaGrue, Wells, and XL723 had greater percentages of chalkiness among cultivars. The mean percent kernel chalkiness differed among the long-grain cultivars ($P < 0.0001$); XL723 had the greatest chalkiness (10.1%), followed by LaGrue with 8.1%, 6.6% for Wells, and 4.2% for Cypress in 2007. In 2008, Jupiter had the least chalkiness and XL723 was the chalkiest. In 2008, long-grain cultivars Cypress, LaGrue, and Wells did not differ in chalkiness. LaGrue, a highly susceptible cultivar to kernel chalk formation in 2007, had a much lower level in 2008, wherein its chalk level was similar to Cypress and Wells. XL723 remained most highly susceptible to kernel chalk formation in 2008.

Overall, chalkiness in brown rice kernels in 2007 was more than twice that of 2008 for Cypress, Jupiter, LaGrue, Wells, and XL723 (Fig. 1). The lower chalkiness in 2008 can be attributed to lower nighttime temperatures in that year (data not shown). Figure 1 shows that when environmental conditions induced chalk formation in rice kernels in 2007, all cultivars responded, but LaGrue, Wells, and XL723 responded more dramatically than the other cultivars used in this study. In 2008, when there were low levels of chalk, none of the cultivars had great chalkiness levels. Thus, these results suggest that when conditions prompt chalk formation, some cultivars respond much more dramatically than others.

By visual inspection, white core and white belly (Juliano, 2003) were the predominant forms of chalkiness among LaGrue, Wells, and XL723 brown rice kernels. For Bengal, Cypress, and Jupiter, white core was predominant among chalky kernels with some translucent kernels bearing white tips and white belly. For Bengal, Cypress, Jupiter, and Wells, most of the chalky kernels were thin and immature, unlike those for LaGrue and XL723 where white core were also observed in mature kernels.

Chalkiness and Peak HRYs

To obtain an accurate correlation of kernel chalkiness to HRY, adjusted peak HRYs for each year/location/cultivar were plotted against the corresponding chalkiness level; by using the peak HRY, the possible effects of immature and fissured kernels on HRY are minimized or eliminated. Siebenmorgen et al. (2007) described HRY as a quadratic function of HMC, which implies that a maximum or peak HRY at an optimal HMC exists. Figure 2 illustrates the peak HRY for rice cultivar XL723 harvested from Newport in 2007. In 2007, LaGrue sustained a high chalk percentage similar to XL723 (Fig. 1) and lowest adjusted peak HRYs among cultivars (data not shown). Wells had moderate chalk percentage in 2007 but showed similar peak HRYs with XL723, which had much greater chalkiness than Wells. In 2008, similar trends were observed for Wells and XL723, however at lower chalkiness percentage. The case for Wells and XL723 indicated that percent chalk partially explained reduction in HRY.

Figure 3 shows the relationship of adjusted peak HRY to chalkiness for 2007 and 2008 for all locations and cultivars. In both years, adjusted peak HRY decreased with increased chalkiness; there was a significant correlation between adjusted peak HRY and chalkiness in 2007 ($P = 0.004$) and 2008 ($P = 0.01$).

SIGNIFICANCE OF FINDINGS

This study quantified chalkiness levels in brown rice kernels and correlated these levels to HRY for rice cultivars Bengal, Cypress, Jupiter, LaGrue, Wells, and XL723 harvested from five locations in Arkansas in 2007 and 2008. Growing environment impacted kernel chalkiness, which can be attributed to nighttime air temperature during the grain filling stages. Cultivars differed in percent chalk susceptibility; LaGrue and XL723 being the most susceptible and Bengal, Cypress, and Jupiter being the more resistant. Wells was a moderately-susceptible cultivar. Percent chalk in rice kernels was strongly correlated to HRY.

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Table 1. Summary of the number of harvest moisture contents (HMCs) and HMC ranges for rice lots harvested in 2007 and 2008 from the indicated locations in Arkansas.

			Location			
			No. of HMCs; HMC Ranges			
Year	Cultivar	Grain type	Corning	Rohwer	Newport	Stuttgart
			(% w.b.)			
2007	Bengal	Medium	9; 16.6 - 25.7	8; 14.4 - 25.9	9; 19.9 - 25.2	5; 19.9 - 25.0
	Jupiter	Medium	11; 17.5 - 25.8	4; 15.3 - 22.7	6; 20.0 - 25.8	3; 18.6 - 22.4
	Cypress	Long	9; 14.6 - 24.3	3; 13.5 - 20.7	9; 18.0 - 23.4	12; 13.7 - 24.9
	LaGrue	Long	11; 12.0 - 22.8	6; 11.7 - 23.2	9; 16.0 - 23.2	4; 14.5 - 24.2
	Wells	Long	13; 12.6 - 24.4	11; 11.7 - 21.3	10; 15.2 - 24.3	10; 13.4 - 25.7
	XL723	Long	12; 12.7 - 28.3	6; 12.3 - 19.2	15; 15.5 - 24.4	10; 12.6 - 21.0
			Corning	Rohwer	Pine Tree	Stuttgart
2008	Bengal	Medium	13; 14.1 - 25.3	7; 19.0 - 25.5	6; 13.4 - 25.4	18; 12.4 - 25.4
	Jupiter	Medium	18; 13.4 - 26.4	6; 19.6 - 23.9	6; 13.1 - 25.1	16; 12.7 - 25.4
	Cypress	Long	9; 13.2 - 26.3	8; 15.5 - 26.1	7; 13.2 - 25.1	15; 12.5 - 25.1
	LaGrue	Long	4; 13.0 - 21.5	6; 18.6 - 24.8	6; 13.5 - 22.0	13; 11.9 - 22.9
	Wells	Long	19; 13.6 - 25.9	5; 16.1 - 24.7	6; 13.1 - 23.3	15; 12.2 - 25.5
	XL723	Long	11; 13.1 - 24.4	11; 13.8 - 26.3	5; 17.0 - 22.1	17; 12.0 - 22.2

Table 2. Brown rice kernel chalkiness (percent of total projected area of 100 kernels) for cultivars Bengal, Cypress, Jupiter, LaGrue, Wells, and XL723 harvested at the indicated locations in Arkansas in 2007 and 2008. The values are averages of the chalk levels measured at each harvest moisture content (MC) indicated in table 1; the chalk level at each MC was the average of two measurements of 100 brown rice kernels.

Year	Location	Bengal	Jupiter	Cypress	LaGrue	Wells	XL723
2007	Corning	3.9 b[z]	5.4 a	4.6 b	10.1 a	8.3 a	11.9 a
	Newport	3.0 c	2.5 b	3.2 c	4.8 b	4.4 b	7.2 b
	Stuttgart	3.3 bc	3.3 b	4.0 b	5.4 b	5.3 b	10.9 a
	Rohwer	5.1 a	3.4 b	6.4 a	11.1 a	8.2 a	12.6 a
2008	Corning	3.3 a	1.3 a	1.9 b	2.9 a	2.5 ab	4.9 ab
	Pine Tree	2.9 a	1.3 a	1.9 b	2.0 b	2.0 b	4.5 b
	Stuttgart	2.9 a	1.6 a	2.3 b	1.9 b	2.6 ab	5.0 ab
	Rohwer	3.3 a	1.7 a	3.6 a	3.0 a	3.3 a	5.7 a

[z] Mean values in a column within years followed by different letters are significantly different ($\alpha = 0.05$), as determined by a Student's t-test.

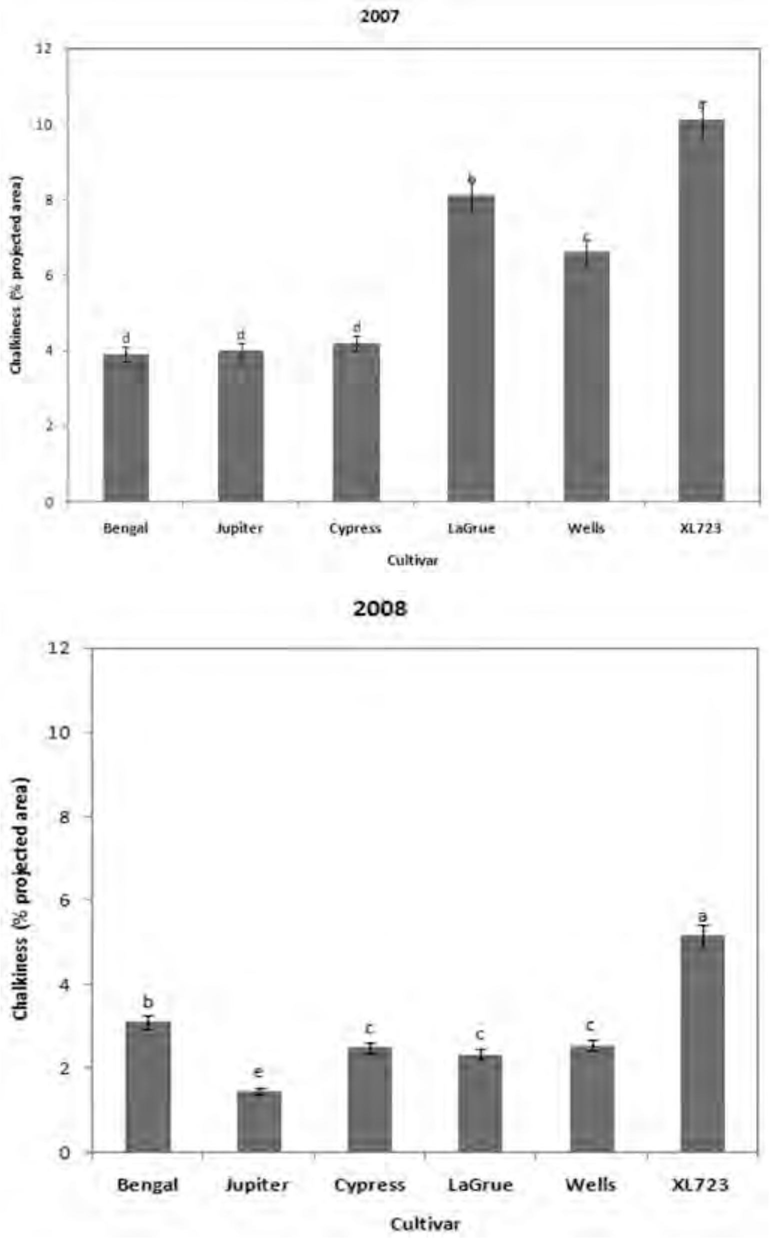

Fig. 1. Brown rice kernel mean chalkiness (percent of kernel projected area) among indicated cultivars with chalkiness levels averaged across the locations and harvest moisture contents in Table 1 for 2007 and 2008. Mean standard errors are indicated. Bars with different letters are significantly different at the 0.05 level as determined by a Student's t-test.

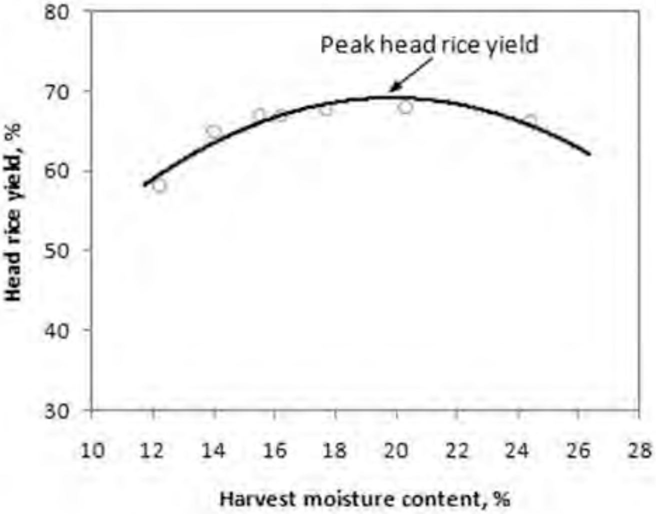

Fig. 2. Head rice yield vs. harvest moisture content plot indicating the peak HRY for rice cultivar XL723 harvested from Newport, Ark., in 2007.

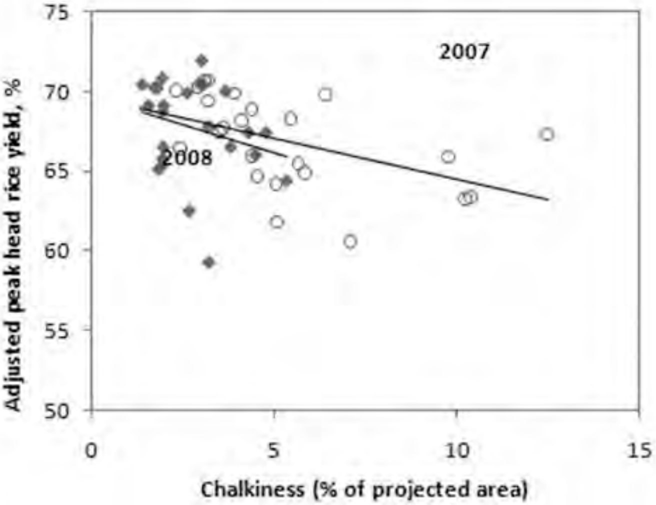

Fig. 3. Adjusted peak head rice yield (Eq. 1 and Eq. 2) correlation to brown rice kernel chalkiness for rice lots indicated in Table 1 for 2007 and 2008. Adjusted peak HRY is the maximum calculated HRY over a range of harvest moisture content indicated in Table 1 for each year/location/cultivar. Each percent chalk data point is the average of two sets of 100 brown rice kernels.

Equilibrium Moisture Contents of Rough Rice Dried Using High-Temperature, Fluidized-Bed Conditions

G.O. Ondier and T.J. Siebenmorgen

ABSTRACT

Equilibrium moisture contents of long-grain rough rice samples with initial moisture content of 20% and dried in a fluidized-bed system at temperatures ranging from 60 to 90 °C and relative humidities from 7% to 75% were measured. Rice sample mass and drying air conditions were recorded throughout the drying duration of each test until a steady-state mass was attained. The Page equation, with experimentally-determined drying parameters, was used to describe the drying data. Equilibrium moisture contents were determined as asymptotic values of the Page model. These equilibrium moisture contents were in turn used to estimate empirical constants of the Modified Chung-Pfost equation, a model commonly used to predict equilibrium moisture content values. The resulting Modified Chung-Pfost equation predicted equilibrium moisture contents with a root mean square error of 0.6182 and a coefficient of correlation of 0.96.

INTRODUCTION

A recent approach to rapid drying of high-moisture content (MC) rough rice utilizes high-temperature, fluidized-bed drying conditions. This technology offers several features: 1) an even flow of fluidized kernels permits continuous, large-scale operations with ease of product handling, 2) high heat and mass transfer rates create rapid movement of moisture from individually exposed kernels to air, and 3) rapid mixing of fluidized kernels leads to uniform drying throughout the fluidized-bed, thus enabling better control of the drying process (Hovmand, 1987).

Fluidized-bed drying has been used commercially for drying rice in Asia, but it has not yet been accepted in the United States. In order to facilitate this possible acceptance, research is needed to fully quantify the kinetics of fluidized-bed rice drying under varying temperature and relative humidity (RH) conditions. A key property necessary for this quantification is the equilibrium moisture content (EMC) of rough rice (Sun and Woods, 1997a, 1997b).

Several studies have reported the Modified Chung-Pfost equation as most appropriate for modeling sorption isotherm data of rough rice and other grains (Iguaz and Versada, 2007; Basunia, 2001). Considering that fluidized-bed drying utilizes drying air temperatures that are not currently used in the drying industry, there is a need to adjust the Modified Chung-Pfost equation for predicting EMCs at these high-temperature conditions. Therefore, the objectives of this study were 1) to measure desorption EMCs of long-grain rough rice subjected to elevated drying air temperatures (60 to 90 °C) in a laboratory-scale, fluidized-bed system; and 2) to adjust the Modified Chung-Pfost equation for predicting equilibrium data of rough rice for the range of temperatures and RHs studied.

PROCEDURES

Test System

A 0.91-m^3 (32-ft^3) environmental chamber (Platinous Sterling Series T and RH Chamber, ESPEC North America, Hudsonville, Mich.) was utilized to produce drying air at set temperature and RH conditions (Fig. 1). The chamber was capable of maintaining air conditions at set levels within a range of temperatures (-35 °C to 150 °C) and RHs (6% to 98%). A metal cylinder, 20.3 cm (8 in.) in diameter and 61.0 cm (24 in.) tall, with a perforated floor to hold rice samples for drying, was mounted to a metal plenum; this drying apparatus was placed inside the environmental chamber. The drying cylinder was wrapped with 2-mm (0.02-in.) thick, ceramic fiber insulation (Zirconia Felt ZY-50, Zircar Zirconia Inc., Florida, N.Y.). A 25.4-cm (10-in.) diameter centrifugal fan (4C108, Dayton Electric Manufacturer Co., Chicago, Ill.), coupled to a 0.56-kW (0.75-hp), three-phase electric motor (3N443BA, Dayton Electric Manufacturer Co., Niles, Ill.), was mounted outside the chamber to avoid high-temperature exposure. This fan suctioned air at a set temperature and RH from the chamber through a port located in the chamber wall, and then exhausted the air into a duct passing through a second port in the chamber wall and connected to the plenum beneath the drying cylinder. The desired airflow rate through the drying cylinder was achieved by regulating the electrical frequency of the fan motor using a frequency inverter (AF-300 Mini, GE Fuji Drives USA, Salem, Va.), which controlled the motor and fan shaft rotational speed.

A spring-loaded damper constructed in the plenum controlled airflow direction by either diverting air through the perforated floor, or by closing off the perforated floor, allowing the air to empty into the environmental chamber. Opening and closing of the spring-loaded damper was controlled by a linear actuator (damper actuator) (LACT4P, SPAL USA, Ankeney, Iowa) mounted outside the environmental chamber and connected to the damper by a cable that passed through a port in the chamber ceiling. A second linear actuator (load cell actuator) (LACT4P, SPAL USA, Ankeney, Iowa) mounted outside the environmental chamber and directly above the drying cylinder was coupled to a 178-N (40-lb_f) full-bridge, thin-beam load cell (LCL-040, Omega Engineering Inc., Stanford, Conn.). The actuator and load cell were attached to the drying cylinder via a cable that passed through a second port in the chamber ceiling.

A 1.11-kg (2.45-lb_m) rice sample, which was required to attain a 5.1-cm (2-in.) grain depth, was placed in the drying cylinder. At specified durations, the damper actuator was activated to raise the spring-loaded damper, thereby preventing airflow through the rice sample. The load cell actuator was then activated to suspend the drying cylinder just above the drying apparatus plenum. After a stabilization period, the mass of the drying cylinder and sample was recorded. The weighing procedure, which lasted 30 s, was repeated at selected intervals during a drying trial until masses remained approximately constant, varying by less than 0.01 g. The drying data were converted to MCs by using the sample mass and MC at the beginning of the drying trial. The MC data were then used to estimate constants *k* and *n* of the Page equation (Page, 1949) (Eq. 1) in order to mathematically model the drying data.

$$MR = \frac{M - M_e}{M_i - M_e} = e^{-kt^n} \qquad (Eq.\ 1)$$

where MR is the moisture ratio, M_i is the initial moisture content, M is the moisture content after a given drying duration, t, hours, M_e is the equilibrium moisture content, and k and n are drying constants.

The asymptotic values of the Page equation were used as EMC values for given air temperature and RH conditions.

Rice Samples

Long-grain rice (‘Cybonnet’) was harvested at the University of Arkansas Northeast Research and Extension Center near Keiser, Ark., on 28 Aug 2007 at approximately 20% MC. The rice was cleaned using a dockage tester (XT4, Carter Day Co., Minneapolis, Minn.) and placed in storage (4 °C) within a day after harvest. Prior to each drying trial, samples were withdrawn from storage, sealed in plastic bags, and allowed to equilibrate to room temperature (20 °C) overnight. The MCs of the rice samples were then measured by drying duplicate, 15-g samples for 24 h in a convection oven (1370 FM, Sheldon Inc., Cornelius, Ore.) maintained at 130 °C (Jindal and Siebenmorgen, 1987).

Rice samples were dried at 60, 70, 80, and 90 °C, and 7, 15, 30, 45, 60, and 75% RH. Three replicates were dried for each condition. A total of 72 drying trials were conducted. Statistical analysis, which included analysis of variance, regression, and student-T, were performed using JMP 8.0.1 (SAS Institute, Inc., Cary, N.C.)

RESULTS AND DISCUSSION

Figure 2 provides a pictorial illustration of how the Page equation (Eq. 1), using experimentally-derived *k* and *n* values, adequately described the experimental data with an average *root mean square error* (RMSE) and *coefficient of* correlation (R^2) of 0.5768 and 0.98, respectively, thus good drying curve estimates were obtained.

Table 1 lists the EMCs determined as asymptotic values of the Page equation for each temperature and RH combination. There were no significant differences (p-values > 0.05) between replications for all drying conditions. As expected, greater EMCs were measured at greater RHs for the same drying air temperature and lesser EMCs were measured at greater temperatures for the same RH. These trends are numerically indicated in Table 1 and pictorially presented in Fig. 3. Similar trends have been reported by Iguaz and Versada, 2007 and Chowdhury et al., 2005. The EMC and RH relationships shown in Fig. 3 were similar to isotherms proposed by Brunauer et al. (1940), where a sigmoid shape (S-pattern) pattern was observed.

Estimates of parameters A, B, and C of the Modified Chung-Pfost (Eq. 2) equation and the indices used to assess the accuracy of the model, namely RMSE and R^2 are shown in Fig. 4. Results indicate that the re-modified Chung-Pfost equation, with statistically estimated parameters (A, B, and C) adequately predicted EMCs for temperatures ranging from 60 to 90 °C. The lesser R^2 (0.96) and greater RMSE (0.6182) compared to values reported in previous studies (Iguaz and Virseda, 2007; Basunia and Abe, 2001) can be attributed to the limited EMC data (total of 72) collected in the study.

$$M_e = \frac{-1}{B} \; Ln \; \frac{-(T + C)LnRH}{A} \qquad (Eq.\ 2)$$

where RH is relative humidity, decimal; T is temperature, °C; Me is equilibrium moisture content (wet-basis); and A, B, and C are grain specific empirical constants.

SIGNIFICANCE OF FINDINGS

The Modified Chung-Pfost equation, with statistically estimated A, B, and C, parameters, can be adequately used to predict the equilibrium moisture contents of long-grain rough rice dried in the range of 60 to 90 °C and 7 to 75% RH. This research could serve in designing and operating fluidized-bed drying systems.

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Table 1. Equilibrium moisture contents, determined as asymptotic values of the Page equation (Eq. 1) for Cybonnet rice samples dried in a fluidized-bed system in the range of 60 to 90 °C and 7 to 75% relative humidities. Each value is an average of three replications.

		Relative humidity					
Temperature	EMC[z]	7	15	30	45	60	75
(°C)	(% wet-basis)	-------------------------------		(%)		-------------------------------	
60	Mean	6.3	7.3	8.4	9.4	10.9	13.1
	Std. dev.	0.06	0.08	0.09	0.26	0.25	0.12
70	Mean	4.9	5.8	6.5	8.2	9.8	12.3
	Std. dev.	0.06	0.03	0.16	0.1	0.04	0.08
80	Mean	4.6	5.2	6.1	7.5	9.4	11.9
	Std. dev.	0.1	0.07	0.2	0.03	0.14	0.11
90	Mean	3.9	4.7	5.4	6.3	8	11.2
	Std. dev.	0.17	0.03	0.13	0.15	0.15	0.14

[z] EMC - equilibrium moisture content.

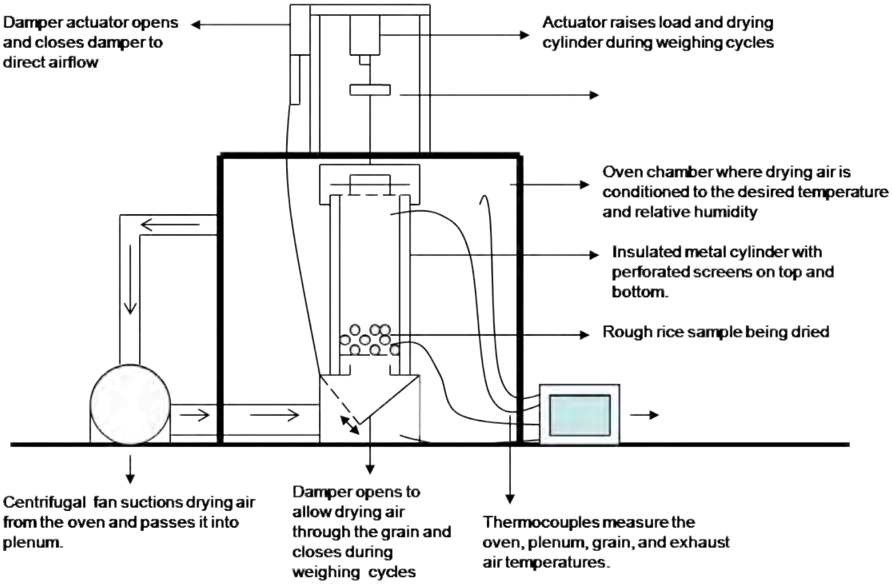

Fig. 1. High-temperature, fluidized-bed drying system.

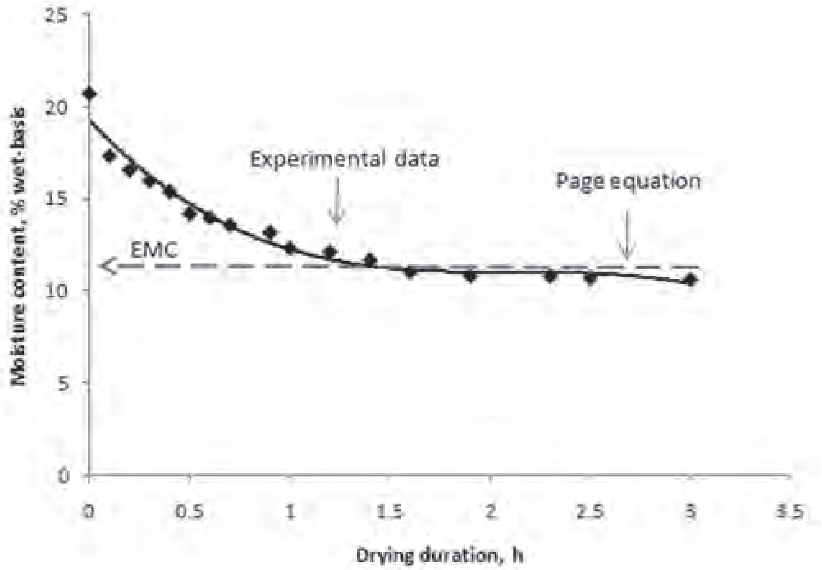

Fig. 2. Illustration of the technique to determine equilibrium moisture content for Cybonnet rice sample dried at 60 °C and 60% relative humidity in a fluidized-bed system. The experimental data are compared to moisture contents predicted by the Page equation (Eq. 1) using experimentally-derived *k* and *n* values.

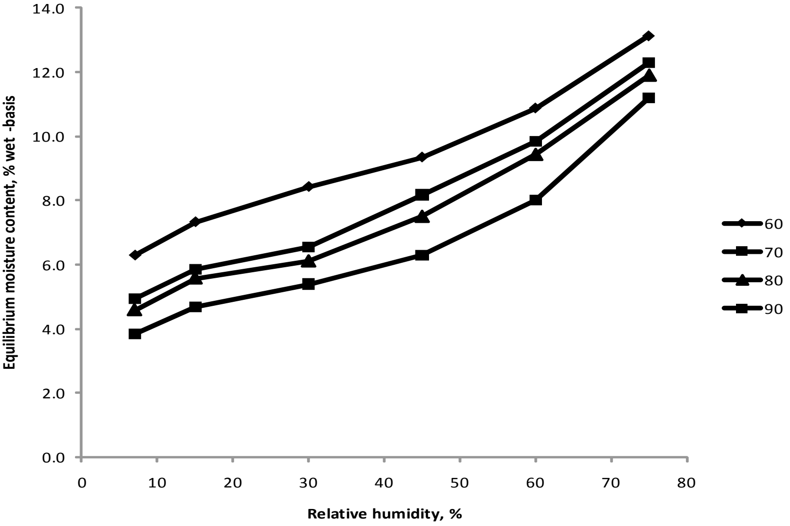

Fig. 3. Equilibrium moisture contents, determined as asymptotic values of the Page equation (Eq. 1) for Cybonnet rice samples dried in the range of 60 to 90 °C and 7% to 75% relative humidities in a fluidized-bed system. Each data point is an average of three replications.

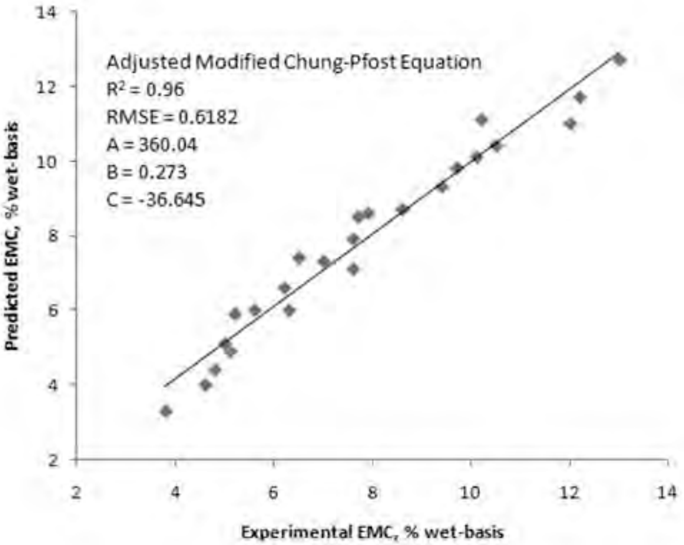

Fig. 4. Linear regression of experimental data, determined as asymptotic values of the Page equation (Eq. 1), and equilibrium moisture contents (EMCs) predicted by the adjusted Modified Chung Pfost equation (with statistically-estimated A, B, and C values) for Cybonnet rice samples dried in the range of 60 to 90 °C and 7% to 75% relative humidities.

ECONOMICS

Environmental Impact, Soil Quality, Grain Yield, and the Economic Viability of a Rice-Soybean Rotation

M.M. Anders and J.A. Hignight

ABSTRACT

The rice-soybean rotation most commonly grown in Arkansas is rarely managed as a no-tillage system. This is due, in part, to the different soil and water requirements of each plant species and little information on how this rotation might respond to no-tillage (NT) as compared to conventional-tillage (CT) and reduced fertilizer inputs. To address this question a rice-soybean rotation has been included in an on-going long-term study. Results after nine years indicate that changing to a no-tillage management system resulted in more runoff but that the runoff from NT management contained significantly less solids, nitrogen, and total phosphorus. Conversion to NT resulted in an increase in soil water-stable aggregates and their associated carbon and nitrogen. This increase was limited to the top 2.5 in. of the soil layer. Soil resistance was significantly reduced below 7 in. in the NT treatment when compared to the CT treatment. Rice grain yields averaged 4 bu/acre less in the NT treatment over the nine year period while there was no difference in fertility levels. 'Wells' grain yield has slowly declined over the nine year period. Soybean grain yield steadily increased in both tillage treatments, but the increase was greatest for the NT treatment. For both crops, grain yields were less variable in the NT treatment. Returns above total costs were greatest for the NT rice and soybeans with the biggest gain in soybean returns. Increasing fertility did not result in greater returns above fertilizer costs for both crops. These results indicate that moving from CT to NT in a rice-soybean rotation will not reduce profits and, simultaneously, soil quality and environmental concerns can be addressed.

INTRODUCTION

A majority of rice grown in Arkansas is grown in a rice-soybean rotation (Wilson and Runsick, 2009). This rotation has been shown to be profitable (Hignight et al., 2009) and is the target rotation for a majority of production recommendations. There is now some pressure to make management changes in this rotation that will address environmental concerns. One of those changes will be the introduction of reduced tillage practices and possibly NT production. Adopting this change will not be easy because each of the two crops in this rotation have specific water and soil requirements that are not compatible, making it difficult for farmers to adopt minimum- and no-tillage practices. This study is an attempt to better understand the dynamics of environmental impact, soil quality, grain yield, and the economic viability of a rice-soybean rotation that has been managed as NT over an extended time period. Our initial hypothesis was that there would be significant monetary losses when treatments such as NT and reduced fertility levels were imposed on this system.

PROCEDURES

A long-term rotation study containing tillage, fertility, and variety comparisons was initiated at the University of Arkansas Division of Agriculture Rice Research and Extension Center in 1999. The study location was cut to a 0.15% slope in February of 1999. Soil at the site is characterized as a Stuttgart silt loam and classified as a fine, smectitic, thermic Albaqultic Hapludolf. Initial soil samples had a pH range of 5.6 to 6.2 with carbon content averaging 0.84% and nitrogen 0.08%. Plots measuring 250 ft × 40 ft were laid out in a north-south direction. These plots were then divided in half east-west with each side randomized as conventional-or no-till treatments. Each tillage treatment was then split into low- and high-fertility treatments. For rice, 'low' fertility consisted of a single pre-flood N application of 100 lb urea/acre plus 40 lb P_2O_5/acre and 60 lb K_2O/acre applied prior to planting. Rates increased to 150 lb N/acre, 60 lb P_2O_5/acre, and 90 lb K_2O/acre for the 'high' treatment with application times remaining the same. Two varieties of each crop species were planted in a continuous strip across the conventional-and no-till treatments. The following rotations that started in 1999 were continued: 1) continuous rice, 2) rice-soybean, 3) soybean-rice, 4) rice-corn, 5) corn-rice, 6) rice (wheat) rice (wheat), 7) rice (wheat)-soybeans (wheat), 8) soybeans (wheat)-rice (wheat), 9) rice-corn-soybeans, and 10) rice-soybeans-corn. Data presented in this paper were collected from the rice-soybean rotation between 2000 and 2009. Both rotation phases were present each year thus data on the rice phase was available every year.

Procedures utilized to collect and calculate runoff data are presented by Harper (2006). Data on soil water-stable aggregates and their associated carbon and nitrogen content along with soil strength were collected in 2005 and are described by Schmid (2008). Data on crop yields and field operations have been collected each year and are summarized. All individual data points were fitted with a distance weighted least-squares (DWLS) fit to indicate yield trends from year to year. The same data set was then fitted with a linear equation to describe the nine-year trend. Pooled data were used to determine average, maximum, minimum, standard deviation (SD) and coefficient of variation (CV) values. Data presented on economic returns were calculated for this report from yield and field operation data collected from 2000 to 2009.

RESULTS

Environmental Impact

There is concern at the state and federal levels that crop production is responsible for, or contributes to, environmental problems associated with pollutants entering in and moving down our rivers and streams. One source of this concern is runoff from fields. Conservation tillage and NT are well-known approaches to reduce the transport of soil and nutrients from fields. In 2005 a rainfall event of 2.8 in./hour was applied to CT and NT plots. This was done after the plots had been planted and the rice was at approximately the 3-lf stage. The percentage of runoff in the NT plots was 82% while it was 60% in the CT plots (Table 1). Greater runoff from the NT treatment is attributed to higher soil moisture levels and an existing residue cover in the NT treatment. Water quality analysis indicated that water from the NT treatment contained 0.03% solids, while that from the CT treatment contained 0.32% solids. These results show that while there is more water moving off the NT treatment, that water contains significantly fewer solids. The greater solids content of water moving off the CT treatment resulted in a turbidity value of 989 while that from the NT treatment was 56. These results indicate that there is a significantly greater amount of soil moving off the CT treatments. Phosphorus movement in waterways is a major concern. This movement can be through phosphorus in the water solution or phosphorus bound to soil moving off the field. The concentration of P measured in runoff was 0.55 ppm for NT and 0.038 ppm for CT. This indicates there is significantly more soluble P being carried off the NT treatment. This result is attributed to the fact that P fertilizer remains on the soil surface in the NT treatment, while it is incorporated in the CT treatment. When total P (soluble plus soil bound) moving off the plots was measured, there was 0.81 ppm in the NT treatment and 1.03 ppm in the CT treatment. These results show that total P movement off the CT plots was primarily from P that was bound to the soil moving with the runoff water. Soil P movement was sufficiently greater in the CT treatment and resulted in significantly less total P moving off the NT treatment. These results show that using NT management will significantly reduce the amount of soil and P moving off fields in a rice-soybean rotation.

Soil Quality

Soil quality can be measured by determining the amount of water-stable aggregates contained in the soil along with their respective carbon and nitrogen contents.

When water-stable aggregate content increases, there is better water movement into and through the soil along with enhanced root penetration. Soil fertility is improved with increased aggregates through greater CEC values and nitrogen content. Increasing water-stable aggregates will increase soil carbon content and carbon sequestration. In this study we report results from soil collected in the top 2.5-in. soil layer five years following treatment initiation. When the water-stable aggregates were separated into five size classes there were a significantly greater percentage of water-stable aggregates in the NT treatment compared to the CT treatment for all size classes (Table 2). When totaled, there were 16% water-stable aggregates in the NT treatment compared to 7.18% in the CT treatment. This indicates more than doubling of the water-stable aggregates in a time period of five years in the NT treatment when compared to the CT treatment. Aggregate carbon and nitrogen content was greater in the three larger aggregate size classes for the NT treatment indicating enrichment of these aggregates. In all but the largest aggregate size class,the C/N ratio was greater in the CT treatment compared to the NT treatment. This suggests that nitrogen contained in the aggregates would be more available in the NT treatment.

Increasing soil aggregates in the NT treatment indicates there should be a corresponding decrease in soil resistance to root growth. Measurements indicate that to be the case (Fig. 1). Soil resistance near the soil surface (< 5 in.) was the same for both tillage treatments. Between 7 and 23 inches in depth there was a significant reduction in soil resistance in the NT plots. Soil resistance values in the CT treatment are sufficiently high to reduce root penetration. This will not impact rice growth as much as soybean growth in a rice-soybean rotation. The soybean grain yields that have steadily increased in the NT plots are associated with the steady improvement in soil quality. At the time the soil resistance measurements were taken, soil moisture was also measured and there was more soil moisture in the NT plots as well (data not presented).

Grain Yield

For the nine years of data reported here, rice grain yields averaged between 180 and 185 bu/acre (Fig. 2) which is about 20 bu/acre greater than the state average yield. Grain yields from the CT treatment averaged 183 bu/acre and have decreased slightly over time. Grain yields for NT averaged 179 bu/acre over the nine years but have increased slightly over time. The highest individual grain yield was a NT treatment, while the lowest was a CT treatment. These results show that, over the nine years, there was little yield difference between the tillage treatments and that statistical differences between these treatments within each year did not reflect overall trends.

There was not a statistical difference between fertility treatments for any of the individual years (data not shown). There has been a slight decrease in grain yields in the low-fertility treatment while those in the high-fertility treatment have gradually increased. These trends are slight and masked by differences between years. They do suggest that there was little or no gain in production from increasing fertilizer rates during the nine years of this study.

The variety 'Wells' was included in every year of this study. Grain yields averaged 182 bu/acre over the nine years but have declined steadily through the nine years. We do not know why this decline has occurred. At the same time grain yields were declining in Wells, they were steadily improving in the plots that first contained 'Lagrue', then 'Cybonnet', and finally 'XL723'. This trend is attributed to the high grain yields of XL723 in the last three years of the study. Grian yields from Cybonnet were lower than expected, thus it was replaced with XL723. These data suggest that it might be useful to consider not growing the same variety at the same location for a long period of time.

Soybean grain yields increased throughout the nine years of this study (Fig. 3). This increase was greatest for the NT treatment compared to the CT treatment. Lower grain yields at the beginning of the study are attributed to disease problems which were overcome with the inclusion of resistant varieties. This trend of increasing grain yields in the NT treatment did not occur in 2009 when there was excessive rainfall and the NT treatment remained wet much of the summer.

As with rice, there were no statistical differences in grain yields between fertility treatments in any of the nine years. Both treatments trended upwards at approximately the same rate. These results indicate that there was no yield penalty for using a lower fertility rate in this study and that profits will be greater for the low-fertility management.

Variety differences were present and reflect the need to select varieties that will perform in the conditions being tested. There have been consistently good grain yields from 'AG4902' and 'AG4903' and until 2008, a variety was not available that would effectively compete with these varieties.

Rice grain yields were little affected by tillage and fertility treatments in this study, while soybean yields increased in no-tillage plots but did not increase in the high-fertility treatment. These results point to a possibility of increasing profits in a rice-soybean rotation by adopting NT and reducing fertilizer applications.

Economic Viability

Table 3 presents budgets for NT and CT rice, soybeans, and the average of the two in rotation. Gross revenue is calculated using the average yield by tillage practice and a 2010 estimated rice price of $5.65/bu and $8.75/bu for soybeans. Gross revenue for rice is $23/acre greater in CT than NT, while NT soybeans averaged $8.75/acre more than CT soybeans. The average gross revenue for the rotation is $724.43/acre for NT and $731.35/acre for CT. The 2010 estimated rice production cost in NT is approximately $11/acre less than CT and $8/acre less in NT soybeans compared to CT. Overall, the rotation production costs are $358.50/acre for NT and $368.49/acre for CT. Deducting all operating costs (production, hauling, drying, and land rent) from gross revenue generates returns above operating costs. Returns above operating costs for both rice and soybeans were greater in NT than CT, although there is less than a $1/acre difference between rice NT and CT returns. The average returns above operating costs for the rotation are $138.30/acre for NT and $130.49/acre for CT. Additional savings can occur under NT with a reduction in fixed costs, which includes depreciation and interest costs on equipment and machinery. Deducting fixed costs from returns above operating costs generates returns above total costs. Returns above total costs would be the returns available to pay for risk premiums, management costs, and overhead expenses. Returns above total cost for rice are approximately $18/acre greater for NT than CT and $34/acre greater for NT soybeans than CT. The average returns above total cost for the rotation are $75.30/acre for NT and $48.99/acre for CT.

Average rice grain yields for the fertility treatments were equal, therefore gross revenue is also equal (Table 4). Soybean yields in the high-fertility treatment averaged 1 bu/acre greater than the low-fertility treatment. The average gross revenue for the rotation is $730.08/acre for the high-fertility treatment and $725.70/acre for the low-fertility treatment. The high-fertility treatments did not yield enough to cover the additional costs compared to the low-fertility treatments for both crops. Average return above fertilizer costs for the rotation is $595.79/acre for the high-fertility treatment and $639.70/acre for the low-fertility treatment. Applying the low-fertility treatment input quantities would save $44/acre relative to applying the high-fertility treatment input quantities in the rotation.

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Table 1. Runoff, total solids, turbidity, solute phosphorus, and total phosphorus (P) from conventional-tillage and no-tillage plots in a rice-soybean rotation.[z]

Tillage treatment	Runoff	Total solids	Turbidity	Solute P	Total P
	-------------- (%)	-----------	(NTU)	------------(ppm)	-----------
No-tillage	82	0.03	56	0.50	0.81
Conventional-tillage	60	0.32	989	0.04	1.03

[z] Harper, T.W., T.C. Daniel, M.M. Anders, and N. Slaton.

Table 2. Soil water-stable aggregates, aggregate carbon and nitrogen content, and the carbon/nitrogen ratio for five aggregate size classes of soil collected from no-tillage and conventional-tillage treatments in a rice-soybean rotation.

Tillage treatment	Sieve size	Aggregates	Carbon	Nitrogen	C/N
	(mm)	-------------------------	(%)	-----------------------	(ratio)
No-tillage	> 4	0.45	2.84	0.24	12:1
Conventional-tillage	> 4	0.20	0.67	0.06	11:1
No-tillage	2	0.62	3.66	0.26	14:1
Conventional-tillage	2	0.40	1.92	0.10	19:1
No-tillage	1	1.20	4.60	0.34	14:1
Conventional-tillage	1	0.52	4.20	0.25	17:1
No-tillage	0.5	2.60	3.18	0.26	12:1
Conventional-tillage	0.5	0.88	3.41	0.25	14:1
No-tillage	0.25	11.38	1.53	0.16	10:1
Conventional-tillage	0.25	5.18	1.84	0.17	11:1
LSD values[z]		0.32	0.46	0.003	0.88

[z] LSD values calculated at a significance level of $P < 0.05$.

Table 3. Estimated 2010 cost and returns in a rice-soybean rotation by crop and tillage practice.

	Rice		Soybeans		Average	
	NT[z]	CT	NT	CT	NT	CT
Gross revenue[y]	$1,011.35	$1,033.95	$437.50	$428.75	$724.43	$731.35
Operating costs						
Production costs[x]	$473.59	$485.08	$243.41	$251.89	$358.50	$368.49
Hauling/drying	$82.03	$88.30	$11.00	$10.78	$46.51	$49.54
Land rent[w]	$252.84	$258.49	$109.38	$107.19	$181.11	$182.84
Returns above operating costs	$202.89	$202.08	$73.71	$58.89	$138.30	$130.49
Fixed costs[v]	$74.00	$92.00	$52.00	$71.00	$63.00	$81.50
Returns above total costs	$128.89	$110.08	$21.71	-$12.11	$75.30	$48.99

[z] NT = no-till and CT = conventional-till.

[y] Gross revenue is yield times prices with rice projected to be $5.65/bu and soybeans to be $8.75/bu for 2010.

[x] Estimated 2010 costs such as seed, fertilizer, herbicides, fuel, labor, etc.

[w] Assumed to be a 25% crop share.

[v] Includes the costs of depreciation and interest on equipment and machinery.

Table 4. Estimated 2010 returns above fertilizer cost by crop and fertility treatment.

	Rice		Soybeans		Average	
	HF[z]	LF	HF	LF	HF	LF
Gross revenue[y]	$1,022.65	$1,022.65	$437.50	$428.75	$730.08	$725.70
Fertilizer costs[x]						
Urea	$77.26	$51.43	$0.00	$0.00	$38.63	$25.72
Phosphate	$26.65	$17.84	$27.47	$17.63	$27.06	$17.74
Potash	$45.00	$30.00	$60.00	$30.00	$52.50	$30.00
Application	$26.69	$19.61	$5.50	$5.50	$16.10	$12.56
Returns above fertilizer costs	$847.05	$903.77	$344.53	$375.62	$595.79	$639.70

[z] HF = high fertility and LF = low fertility.

[y] Gross revenue is yield times price with rice projected to be $5.65/bu and soybeans to be $8.75/bu for 2010.

[x] Fertilizer per unit costs based upon the University of Arkansas's 2010 crop production budgets.

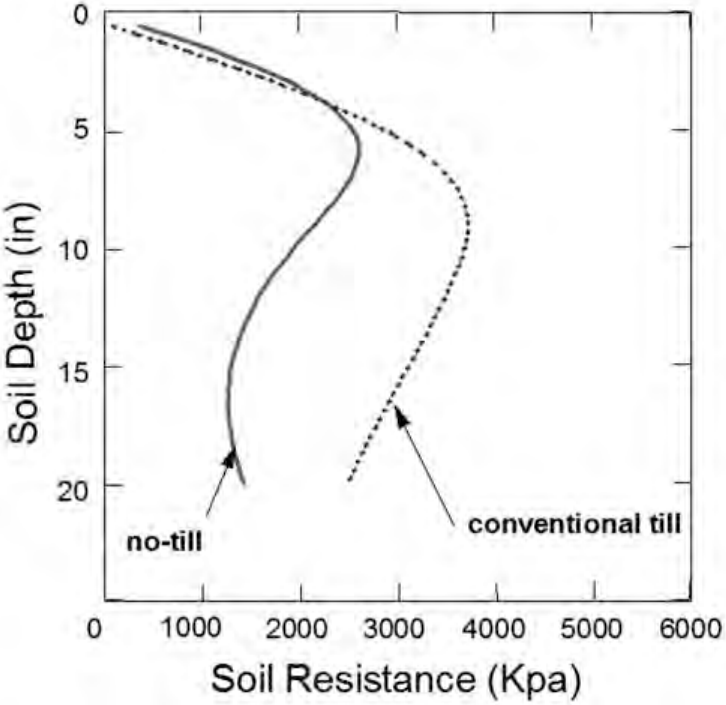

Fig. 1. Soil resistance for a conventional- and no-till rice-soybean rotation five years following initiation of treatments.

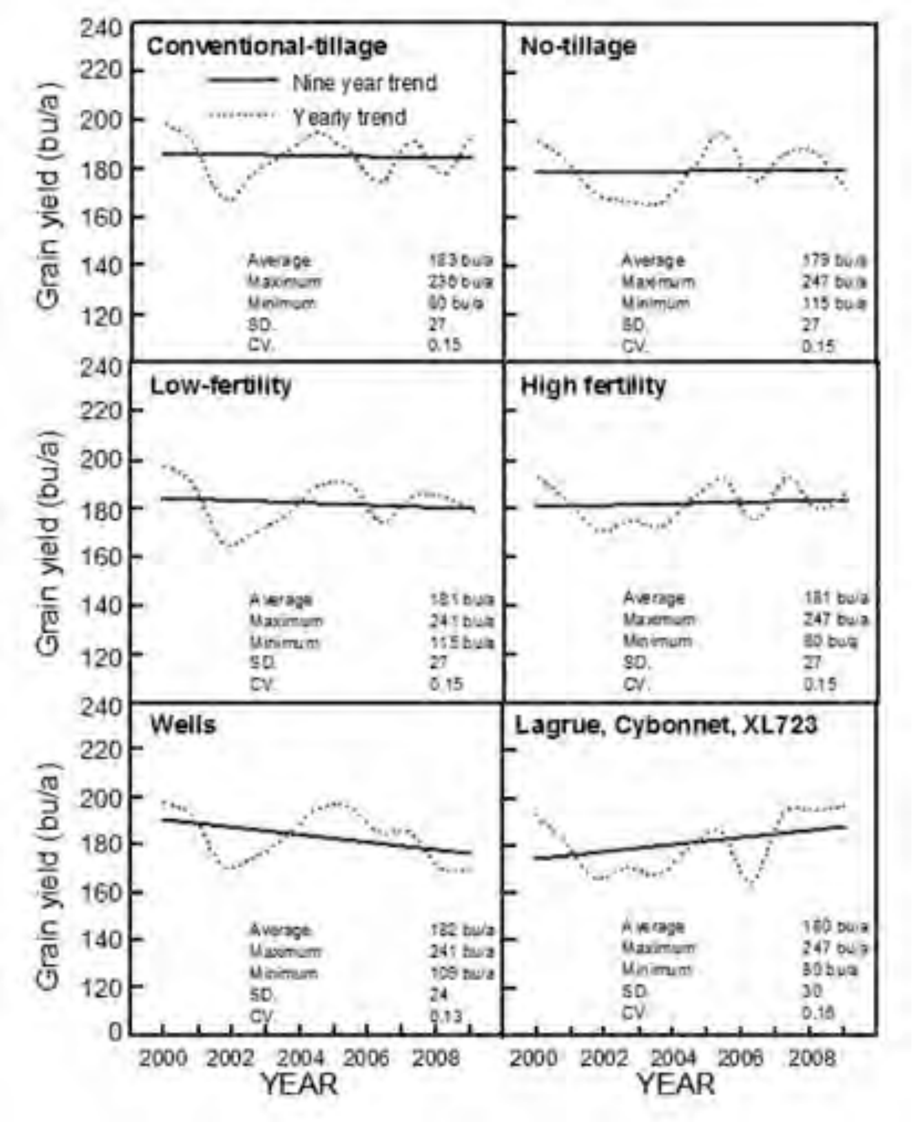

Fig. 2. Seasonal and yearly rice grain yield trends for a rice-soybean rotation that was managed as no-till or conventional-till, low-fertility or high-fertility, into the varieties of Wells or LaGrue, Cybonnet, or XL723.

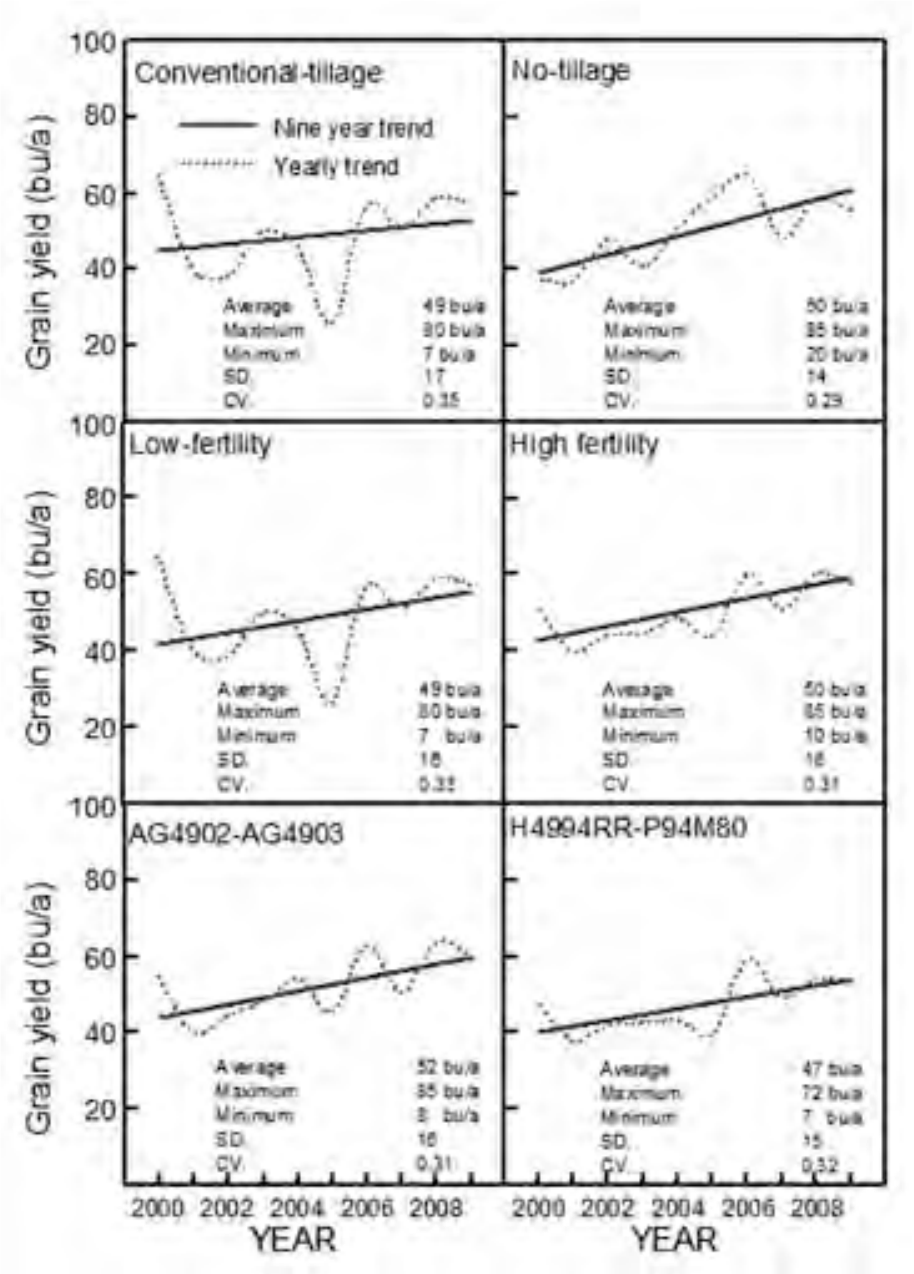

Fig. 3. Seasonal and yearly soybean grain yield trends for a rice-soybean rotation that was managed as no-till or conventional-till, low-fertility or high-fertility, into the varieties of AG742-AG743 or H4994RR-P94M80.

ECONOMICS

An Economic Risk Comparison of Tillage and Fertility in Continuous Rice, 2000 to 2009

J.A. Hignight, K.B. Watkins, and M.M. Anders

ABSTRACT

From 2000 to 2009, an ongoing continuous rice study comparing no-tillage to conventional tillage with two different fertility treatments has been conducted at the University of Arkansas Division of Agriculture Rice Research and Extension Center (RREC). Four treatments were analyzed from this study. They included no-tillage high fertility (NT-HF), no-tillage low fertility (NT-LF), conventional-till high fertility (CT-HF), and conventional-till low fertility (CT-LF) treatments. Average rice grain yields were greatest (162 bu/acre) for the CT-HF treatment combination and lowest (142 bu/acre) in the NT-LF treatment combination. Continuous rice grain yields indicate that CT has an agronomic advantage over NT. Higher fertility rates did not improve rice yields sufficiently to pay for the additional fertilizer costs. Variability in grain yield was least for CT-LF and highest for NT-HF treatment combinations, respectively. Variable costs averaged the least for NT compared to CT although these cost savings were not sufficient to offset yield losses in NT-LF compared to CT-LF. Results indicated that returns above total costs on average were greatest for CT-LF ($89/acre) followed by NT-LF ($71/acre), NT-HF ($57/acre), and CT-HF ($36/acre).

INTRODUCTION

Rice is Arkansas' highest valued crop and accounts for nearly half of U.S. total production (USDA). Rice is typically rotated with soybeans although some acres are continuous rice or rotated with other crops such as corn, sorghum, cotton, and wheat. In 2002, no-tillage (NT) rice production in Arkansas was estimated at 9% (Wilson and Branson, 2002) and increased to 16% by 2008 (Wilson and Runsick, 2009). No-tillage has been shown to reduce labor, fuel, and machinery costs as compared to conventional-tillage (CT) (Epplin et al., 1982; Krause and Black, 1995). Some of these costs savings may be offset by increased herbicide use and lower crop yields. Reductions of these costs should favor the use of NT crop management in Arkansas, but adoption has lagged well below the national adoption rate. The lack of adoption may be attributed to potential management issues, fear that grain yields will be significantly less than CT, and limited profit and risk information.

Fertility recommendations usually are designed to maximize the agronomic yield. The University of Arkansas Division of Agriculture recommendations on nitrogen (N) for continuous rice production on silt loam soils are 170 lb N/acre for conventional varieties and 140 lb N/acre for hybrid varieties (Wilson, 2007). Phosphorus and potassium recommendations are generally made based upon the Mehlich-3 soil test method for a particular field (Wilson et al., 2001). Generally, nitrogen is considered the most important nutrient in rice production for increasing yield, assuming that phosphorus, potassium, and micro-nutrients are not limiting factors on productivity.

The objective of this study is to compare profitability and risk of NT and CT in continuous rice. The study looks at four management options: 1) no-tillage with high fertility (NT-HF), no-tillage with low fertility (NT-LF), conventional tillage with high fertility (CT-HF), and conventional tillage with low fertility (CT-LF).

PROCEDURES

The field trials were conducted at the University of Arkansas Rice Research and Extension Center (RREC), Stuttgart, Ark. The plot location was cut to a slope of 0.15% in February of 1999. Soil at the site is referred to as a Stuttgart silt loam and classified as a fine, smectitic, thermic Albaqultic Hapludof. Initial soil samples show a pH range of 5.6 to 6.2 with carbon content averaging 0.84% and nitrogen 0.08%. Plots measuring 250 ft × 40 ft were laid out in a north-south direction. These plots were then divided in half east-west with each side randomized as conventional or no-till treatments. Each tillage treatment was then split into a low- and high-fertility treatment. For rice, 'low' fertility consisted of a single pre-flood N application of 100 lb/acre, 40 lb P_2O_5/acre, and 60 lb K_2O/acre while rates for the 'high' fertility increased to 150 lb N/acre, 60 lb P_2O_5/acre, and 90 lb K_2O/acre. For the no-till treatment, all plant residues were left on the plots while conventional-till plots were burnt following harvest. Phosphorus and potassium fertilizers were applied prior to planting with both fertilizers incorporated with tillage in the conventional-tillage plots and left on the soil surface in the no-till plots.

Actual yields from the study are presented in Table 1. Summary statistics of simulated yields by tillage and fertility are presented in Table 2 along with rice price, and key input prices. Prices come from the United States Department of Agriculture National Agricultural Statistical Service (NASS). Ten years of yield and NASS price data were detrended using linear regression and the residuals were used to simulate risk. Yield residuals were simulated around the mean of the ten years of data while price residuals were simulated around a three-year average to represent price volatility producers could currently encounter. Additional variable costs and fixed costs data came from the NASS, Economic Research Service (ERS), and input costs data gathered by University of Arkansas extension economists.

The rice yields and prices were simulated 500 times by creating multivariate empirical distributions using the Excel™ add-in SIMETAR. Simulating grain yields within the parameters of the real data gives a range of possibilities that could occur and allows risk analysis between tillage and fertility. Gross revenue was calculated by multiplying crop price and average yield per acre. Returns above variable costs (RAVC) and returns above total costs (RATC) were both calculated. Returns above variable costs are calculated by deducting the variable costs from the gross returns per acre. Returns above total costs are equal to RAVC minus the fixed or ownership costs per acre of machinery and equipment. Returns above total costs do not include management, overhead, and risk premium costs. The analysis does include land rent which is 25% of gross revenue and is deducted when calculating RAVC.

RESULTS AND DISCUSSION

Summary statistics for the results are presented in Table 3. The tillage and fertility treatment results include gross revenue, variable costs, returns above variable costs, and returns above total costs. Included in the summary statistics are the mean, standard deviation, coefficient of variation, minimum, and maximum.

Gross revenue (GR) is a function of yield multiplied by price. The CT-HF treatment had the highest gross revenue per acre at $991 followed by CT-LF ($976), NT-HF ($966), and NT-LF ($893). Comparing relative risk with the coefficient of variation (CV) indicates that the CT treatments had the same relative risk (26), while the NT treatments risk of GR variability was slightly larger at 27 and 28 for NT-LF and NT-HF, respectively. Lower CVs indicate less relative variability, while higher CVs indicate greater relative variability. Simulated results indicate that NT-LF had the lowest minimum GR per acre at $556, while CT-HF ($618) had the largest minimum. The largest maximum GR per acre was obtained in the CT-HF treatment at $1,865, while the lowest maximum was in the CT-LF ($1,714).

Several key input prices were simulated and therefore variable costs (VC) summary statistics are presented in Table 3. Variable costs were lower for NT than CT due to cost savings in fuel, labor, and machinery repair and maintenance. The mean VC was lowest per acre for NT-LF at $540 followed by CT-LF ($567), NT-HF ($609), and CT-HF ($631). The low-fertility treatments had slightly lower relative risk in VC than the high-fertility treatments indicating that the additional fertilizer applied caused greater variability.

Returns above variable costs (RAVC) is a function of gross revenue minus variable costs and land rent. The CT-LF treatment had the highest average RAVC per acre of $165 followed by NT-LF ($129), NT-HF ($116), and CT-HF ($112). The CT-LF treatment had the lowest relative risk, while NT-HF had the highest RAVC variability as measured by the CV. All treatments have a chance of achieving a negative RAVC. The

NT-HF had the lowest minimum per acre at -$257 but also had the largest maximum RAVC per acre at $801.

When machinery and equipment costs are included, the returns above total cost (RATC) results are similar to the RAVC results. The CT-LF treatment had the highest per acre RATC at $89 followed by NT-LF ($71), NT-HF ($57), and CT-HF ($36). Relative variability for RATC was least for CT-LF treatment and greatest for CT-HF. The lowest minimum RATC was obtained for the CT-HF treatment while the largest maximum RATC was obtained in the NT-HF treatment.

Figure 1 presents a stoplight graph of the probabilities RATC will be below $0/acre or above $150/acre. The graph indicates that the CT-HF treatment would have the highest probability of a negative RATC at 52%, while CT-LF had the lowest probability of receiving a negative RATC at 35%. The CT-LF treatment also had the highest chance of obtaining a RATC above $150/acre at 26%.

SIGNIFICANCE OF FINDINGS

Results from this analysis indicate that CT-LF, on average, had the highest RATC followed by NT-LF, NT-HF, and CT-HF. Rice yields in NT averaged below CT over the ten years. Fertility also played a significant part in the average yield. Rice yields typically were greater with the high-fertility treatment as compared to the low-fertility treatment although grain yields were not enough to justify the additional fertilizer costs. It is probable that neither fertilizer treatment was economically optimal for maximizing returns. For example, the high nitrogen rate along with the lower rates of potassium and phosphorus may have resulted in higher returns. Overall, the results indicate that CT-LF is more profitable than NT but other factors should be considered. Yields in NT have averaged better than CT in the previous five years and the trend may continue, making NT more profitable than CT, over time.

ACKNOWLEDGMENTS

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Table 1. Measured grain yields for continuous rice by treatment and year.

Year	NT-HF[z]	NT-LF	CT-HF	CT-LF
2000	146	138	170	166
2001	150	128	152	148
2002	122	121	152	135
2003	137	122	140	155
2004	145	144	171	164
2005	190	179	165	175
2006	164	158	164	159
2007	179	169	192	177
2008	180	150	149	158
2009	157	142	161	152
Average	157	145	162	159

[z] NT = no-till; CT = conventional-till; HF = high-fertility; and LF = low-fertility.

Table 2. Summary statistics for yields, crop price, and input prices.

	Unit	Mean[z]	SD[y]	CV[x]	Minimum	Maximum
Rice yields						
NT-HF[w]	bu/acre	157	16	10	131	187
NT-LF	bu/acre	145	15	10	127	177
CT-HF	bu/acre	162	13	8	141	190
CT-LF	bu/acre	159	11	7	137	174
Crop prices						
Rice	$/bu	6.09	1.41	23.22	4.39	9.84
Input prices						
Potash	$/lb	0.38	0.32	83.37	0.17	1.30
Phosphate	$/lb	0.33	0.11	32.74	0.22	0.57
Urea	$/lb	0.25	0.04	15.55	0.19	0.33
Diesel	$/gal	2.59	0.61	23.45	1.61	3.74
Glyphosate	$/pt	4.68	5.43	14.50	3.64	5.83

[z] Average from the 500 simulated iterations.
[y] Standard deviation.
[x] Coefficient of variation (CV).
[w] NT = no-till, CT = conventional-till, HF = high-fertility, and LF = low-fertility.

Table 3. Summary statistics of results for continuous rice.

Treatment	Mean[z]	SD[y]	CV[x]	Minimum	Maximum
Gross revenue ($/acre)					
NT-HF[w]	966	266	28	575	1,841
NT-LF	893	245	27	556	1,740
CT-HF	991	258	26	618	1,865
CT-LF	976	259	26	601	1,714
Variable costs ($/acre)					
NT-HF	609	67	11	497	849
NT-LF	540	49	9	452	719
CT-HF	631	68	11	518	878
CT-LF	567	51	9	472	745
Returns above variable costs ($/acre)					
NT-HF	116	180	155	-257	801
NT-LF	129	164	127	-160	777
CT-HF	112	172	153	-245	723
CT-LF	165	171	104	-150	733
Returns above total costs ($/acre)					
NT-HF	57	180	316	-316	743
NT-LF	71	164	232	-219	718
CT-HF	36	172	484	-321	646
CT-LF	89	171	193	-227	656

[z] Average from the 500 simulated iterations.
[y] Standard deviation.
[x] Coefficient of variation (CV).
[w] NT = no-till, CT = conventional-till, HF = high-fertility, and LF = low-fertility.

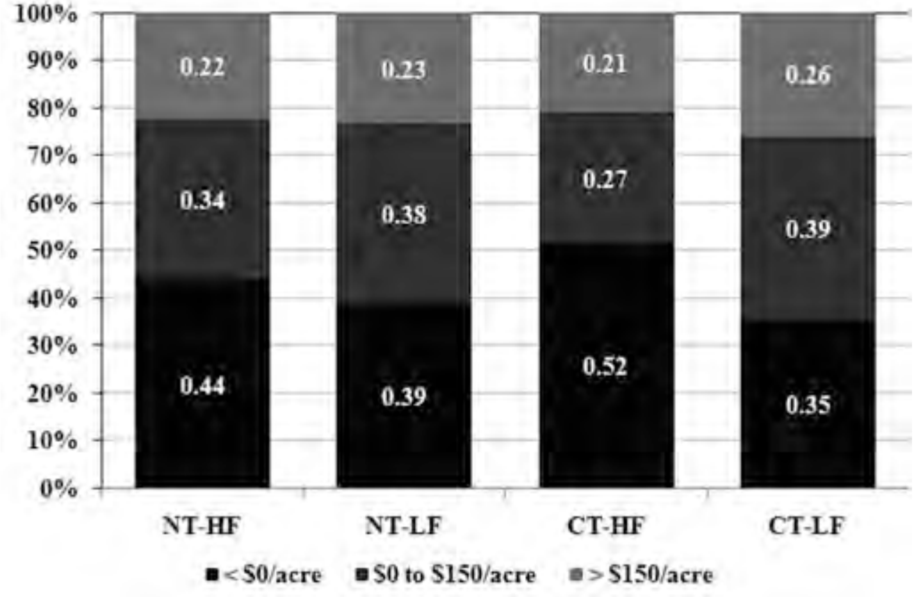

Fig. 1. Continuous rice net return probabilities by return interval and treatment based on 500 iterations.

ECONOMICS

Rice Price and Policy Analytical Baseline, 2010 to 2019

E.J. Wailes and E.C. Chavez

ABSTRACT

The world rice prices weakened in the marketing year 2009-10 as more exportable supplies became available, even as major rice exporting countries like India, Egypt, Pakistan, China, and Thailand maintained export restrictions and stock controls. In recent years, the role of the Thai 100%B as a world reference price has become limited because of competitive pressure from Vietnamese rice exports; therefore the world reference price (net trade equilibrium price) used in the Arkansas Global Rice Model (AGRM) baseline does not rely on the Thai price to equilibrate world rice trade. With an assumption of a return to normal weather patterns, export prices are expected to further weaken in 2010-11 and 2011-12 as exportable supplies expand. However, resource constraints such as higher input prices and limitations on land and water for irrigation are expected to cause rice prices to increase gradually over the baseline, driven by growth in consumption and trade. Population-driven consumption growth keeps the global rice stocks-to-use ratio between 19% and 21% over the baseline. Over the next decade, total global rice trade is projected to grow by 2.8% annually, reaching 41.3 million metric tons in 2019-20. India, Thailand, Pakistan, and Vietnam are projected to account for 81.2% of the volume growth in world rice net exports. With strong growth in population and per capita rice consumption, rice imports in Africa and the Middle East continue to increase substantially, accounting for 50.4% of the total volume growth in world rice imports over the next decade.

INTRODUCTION

Prices for U.S. rice are heavily influenced by the global rice economy. Supply, demand, trade and stocks as well as policies in the U.S. and other major exporters and importers determine rice price paths. This study provides an assessment of the primary driving forces that are expected to determine rice prices and trade over the next decade. This research is conducted in collaboration with the Food and Agricultural Policy Research Institute (FAPRI) at Iowa State University and the University of Missouri-Columbia to provide U.S. policy decision-makers and the rice industry with a baseline framework by which to evaluate the impact of alternative policies and changes in market and technology.

PROCEDURES

We use the Arkansas Global Rice Model (AGRM), a multi-country econometric model developed and maintained by the Rice Economics Policy Group in the Department of Agricultural Economics and Agribusiness at the University of Arkansas, to generate projections of international rice production, consumption, trade, and prices for the period 2010 to 2019. The AGRM covers 40 countries, including new models for Cambodia and nine additional African countries in 2009. Macroeconomic assumptions in the FAPRI baseline for national income, population, exchange rates, price and income deflators, and energy prices are provided by Global Insight and are used exogenously to develop 10-year baseline projections for all major grains, oilseeds, cotton, sugar, and livestock. The framework for rice is developed and maintained by the authors in collaboration with other researchers at Iowa State University and the University of Missouri who maintain the other agricultural commodity models of the Food and Agricultural Policy Research Institute. The 2010 baseline was initiated in November 2009 with the researchers of the consortium participating in a week-long intensive workshop to iterate all the models to develop a preliminary baseline that is presented and evaluated in Washington, D.C. by commodity and policy experts from various U.S. and international government agencies. Following this evaluation, the final baseline was developed during another week-long workshop in January 2010. This baseline is made public for use by congressional committees and their staffs, USDA, and other domestic and international government agencies, and other researchers (FAPRI, 2010). The AGRM is a system of over 200 econometric equations that specify functional relationships for area, yields, per capita consumption, trade (exports and imports), stocks, rice policies and prices and exogenous variables including per capita incomes, exchange rates, price and income deflators, and population growth rates.

RESULTS AND DISCUSSION

The world reference rice prices weakened by nearly 12% in the marketing year 2009-10 as more exportable supplies became available, even as major rice exporting countries like India, Egypt, Pakistan, China, and Thailand maintained export restrictions and stock controls to dampen domestic price increases. In this baseline, the price that equilibrates net trade in the model, the so-called world reference price, is used in the projections. This price no longer tracks the Thai 100%B price, as current Thai policies on domestic price, government storage, and government-to-government exports have limited the usefulness of Thai 100%B as a reasonable international reference price for rice. The export price premium of U.S. long-grain rice over the world reference price narrowed to $6/metric ton in 2009-10, as competition from relatively low-priced rice from Vietnam intensified. Vietnam sold rice at a discount by as much as $150/metric ton below the Thai price, making it very competitive in the global rice market (Table 1).

Rice export prices are projected to weaken in 2010-11 and 2011-12 as more exportable supplies become available, and gradually increase over the baseline, driven by strong consumption and trade, reaching $429/metric ton by 2019-20. Population-driven consumption growth keeps the rice stocks-to-use ratio between 19% and 21% over the same period (Table 2).

World rice area in 2009-10 decreased by 2.5% from the previous year's level mainly because of a weather-related drop of 5.2 million hectares in India's area that negated gains in China, Myanmar, Thailand, and Nigeria. While world rice production has outpaced consumption since 2005-06, the situation reversed in 2009-10, as India's output declined by 14.7 million metric tons. During the same period, global rice production declined by 2.7% to 434.7 million metric tons as average yield declined marginally. With global rice yields projected to improve by 2.2% and area to increase by 0.8%, total rice output is projected to recover in 2010-11, expanding by 3.0% to 447.7 million metric tons. Over the baseline, while world rice area is projected to increase only marginally (+0.1%), average milled yield is projected to grow by 0.6%/year, reaching 3.06 metric tons/hectare by 2019-20.

Total world rice consumption in 2009-10 increased by 0.7% to 436.5 million metric tons, as world population grew by 1.1% and average per capita use declined by 0.4%. Substantial consumption gains in China, Bangladesh, and Indonesia were offset by declines in India and Pakistan during the same period. Total world rice trade in 2009-10 was 29.7 million metric tons, up 8.2% from the previous year, as total export shipments from Thailand, Pakistan and China increased substantially. Net world rice trade in 2009-10 was 27.6 million metric tons, up 11.7% from the previous year (Table 1). With world population growth of 1.1% and an increase of 0.7% in per capita use, total global rice consumption in 2010-11 is expected to increases by 1.8%, to 444.3 million metric tons as world rice prices decline. Total world rice trade expands to 32.3 million metric tons during the same period, up 8.9% from the previous year, as more export supplies come from India and Thailand. With increased available supply relative to demand, international rice prices are expected to weaken substantially in 2010-11.

Over the next decade, global rice area increases marginally to 155.7 million hectares and yields continue to improve by 0.6% annually, causing total production to grow by 0.7%. Total consumption continues to increase steadily by 0.8% annually, with the expansion driven solely by population growth as average per capita use declines marginally (Table 3). The decline in per capita use of rice in Asia is a result of the combined effects of the westernization of diets, urbanization, and diet diversification toward more protein-based foods, especially in rice economies with rising incomes such as China, India, Indonesia, Vietnam, Thailand, Japan, South Korea, and Taiwan.

Projected area expansions in India, Bangladesh, Myanmar, and Thailand offset the contractions in China, Japan, and South Korea over the baseline. India's role in the global rice economy is projected to remain prominent because India accounts for 28% of net increase in area over the same period. India also accounts for 38% of the net growth in total production, with 45% coming from Bangladesh, Thailand, Indonesia, the Philippines, Brazil, Myanmar, Cambodia, and Vietnam. Nearly 29% of the net gain in world rice consumption comes from India, with 52% accounted for by Bangladesh, European Union-27, Indonesia, the Philippines, Nigeria, and Myanmar.

Over the baseline, global total rice trade is projected to grow by 2.8% annually, reaching 41.3 million metric tons in 2019-20, 31% higher than the record set in 2006-07 (Table 2). Despite this growth, rice remains thinly traded in the international market relative to other grains, with the share of total trade to total consumption at 8.6% in 2019-20. Most of the growth in trade is accounted for by long-grain rice which expands at 2.3% per year, as demand for medium-grain rice grows slower at 1.3%. Exportable supplies of medium-grain rice are limited and demand is constrained by trade policies. Medium-grain prices reflected in the U.S. No. 2 Medium California fob price in Table 1 maintain a strong premium relative to long-grain prices over the same period. India, Thailand, Pakistan, and Vietnam account for 81.2% of the volume growth in net exports over the next decade. These countries experience declines in rice per capita consumption, which allows yield-based growth in production to outpace domestic consumption. Thailand's growth in production (+1.0%) exceeds domestic consumption growth (+0.2%), enabling Thai rice exports to grow by 1.7% annually. In contrast, growth in domestic rice consumption (+1.2%) in the U.S. outpaces that of production (+0.3%), causing rice exports to decline by 1.5% per year over the same period. Despite its projected substantial contraction in rice area, China is expected to remain a rice net exporter with net exports growing at 3.6% annually, as yields improve and per capita consumption declines. Likewise, Uruguay and Argentina are projected to expand exports, as area gains and yields improve, causing production to substantially exceed domestic use. Yield improvements and a slight increase in area enable Egypt to increase its medium-grain exports by 3.1% per year over the same period. With strong growth in both population and per capita rice consumption, rice imports in Africa and in the Middle East continue to increase substantially, accounting for 50.4% of the total volume growth in world net rice imports over the next decade. Nigeria alone is projected to import 2.8 million metric tons by 2019, while the Ivory Coast, South Africa, and nine other African countries need to import another 1.4 million metric tons over the same period. Rice imports in the Middle East are expected to continue to expand because water availability remains a constraint in rice production in the region. Strong population growth both in Indonesia and Bangladesh causes total rice consumption to expand, despite slightly declining per capita consumption in Indonesia. The Philippines is projected to be the top rice importer over the baseline, as the country's rice self-sufficiency program has yet to attain meaningful traction. Malaysia's rice imports grow at 3.6% per year, as consumption continues to outstrip production. Japan's rice imports, on the other hand, remain flat at the minimum access level of 682,000 metric tons in the absence of any expansion under the WTO. With promising yield improvements due to increased use of hybrids, a trade reversal is projected for Brazil causing the country to become a rice exporter by the end of the baseline period. Common Agricultural Policy (CAP) reforms in the EU result in slow growth in production and an increase in rice imports. Mexican rice imports expand at 3.6% per year, as per capita use continues to grow. Population and income drive the 5.6% annual growth in Turkish rice imports. Irrigation constraints have made Australia a net importer of rice, but its imports are projected to decline at 12.3% annually, as area partially recovers and yields improve gradually during the same period.

SIGNIFICANCE OF FINDINGS

With nearly one-half of the Arkansas rice crop exported to foreign markets each year, a better understanding of the market and policy forces that are driving the global rice economy is important for Arkansas rice producers and millers. Market prices received by Arkansas rice producers are primarily determined by the factors that affect international rice 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 that global commodity trade is transacted. The baseline presented in this report reflects research that brings together in a system of equations the major factors that will affect the Arkansas and U.S. rice economy over the next decade.

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Table 1. World net rice trade and prices.

	09-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	18-19	19-20
	(thousand metric tons)										
Net exporters											
Argentina	591	554	660	650	686	706	724	757	786	810	798
Australia	-176	-173	-129	-95	-62	-59	-66	-63	-60	-57	-53
Cambodia	773	764	711	725	726	696	723	717	733	773	797
China	1,130	1,048	1,139	1,244	1,281	1,324	1,345	1,331	1,352	1,373	1,437
Egypt	432	553	612	629	628	658	672	689	709	710	725
India	1,982	4,436	5,758	5,806	6,170	6,262	6,522	6,751	6,838	6,921	7,072
Myanmar (Burma)	1,007	1,051	1,174	1,248	1,270	1,303	1,328	1,351	1,408	1,448	1,462
Pakistan	3,791	3,062	3,254	3,404	3,457	3,646	3,551	3,550	3,666	3,670	3,766
Thailand	9,798	10,733	11,097	11,136	11,273	11,358	11,535	11,874	12,094	12,366	12,497
United States	2,494	2,462	2,245	2,171	2,137	2,118	2,100	2,073	2,071	2,090	2,152
Uruguay	750	762	786	816	837	858	902	926	940	972	994
Vietnam	5,004	4,575	4,580	4,645	4,553	4,723	4,795	5,133	4,974	5,079	5,057
Total net exports^z	27,576	29,826	31,888	32,378	32,957	33,594	34,133	35,088	35,510	36,155	36,705
Net importers											
Bangladesh	704	954	1,426	1,553	1,664	1,783	1,813	1,849	1,863	1,858	1,854
Brazil	340	691	879	767	659	531	396	269	-29	-223	-533
Cameroon	301	334	370	390	403	410	422	452	464	478	486
Canada	341	357	367	387	409	425	444	460	472	485	493
China - Hong Kong	350	381	385	388	392	396	400	405	408	411	413
European Union-27	1,203	1,360	1,362	1,376	1,390	1,374	1,391	1,414	1,439	1,482	1,539
Ghana	351	370	345	330	307	287	278	275	284	289	299
Guinea	148	222	208	196	185	198	185	204	215	227	235
Indonesia	303	970	1,241	1,217	1,254	1,402	1,401	1,424	1,403	1,422	1,624
Iran	1,701	1,690	1,651	1,655	1,744	1,723	1,855	1,963	1,988	2,086	2,215
Iraq	1,100	1,247	1,253	1,260	1,277	1,297	1,325	1,356	1,389	1,428	1,484
Ivory Coast	796	966	1,034	1,155	1,205	1,240	1,283	1,333	1,360	1,398	1,438
Japan	500	482	482	482	482	482	482	482	482	482	482
Kenya	247	385	355	369	416	415	439	475	483	511	499

continued

Table 1. Continued.

	09-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	18-19	19-20
	(thousand metric tons)										
Net importers, continued											
Malaysia	829	983	1,029	1,044	1,090	1,095	1,125	1,165	1,199	1,247	1,352
Mali	102	204	192	174	165	173	170	177	180	193	188
Mexico	596	658	664	696	728	751	779	810	840	872	902
Mozambique	350	366	383	400	416	430	438	458	465	489	494
Nigeria	1,600	1,943	2,067	2,152	2,242	2,303	2,387	2,501	2,639	2,757	2,800
Philippines	2,599	2,983	2,924	2,891	3,293	3,433	3,397	3,570	3,768	3,859	3,977
Saudi Arabia	1,320	1,411	1,415	1,450	1,488	1,523	1,559	1,595	1,627	1,659	1,688
Senegal	701	573	630	672	711	730	796	841	889	937	986
Sierra Leone	130	162	167	169	169	163	154	148	136	128	111
South Africa	726	978	975	996	1,018	1,038	1,065	1,096	1,121	1,167	1,192
South Korea	300	327	348	368	388	409	409	409	409	409	409
Taiwan	70	108	108	108	108	108	108	108	108	108	108
Tanzania	79	158	147	138	164	173	192	222	217	232	223
Turkey	191	212	238	254	273	284	299	314	325	334	346
Rest of world	9,599	8,352	9,244	9,341	8,918	9,017	9,143	9,315	9,369	9,434	9,399
Total net imports	27,576	29,826	31,888	32,378	32,957	33,594	34,133	35,088	35,510	36,155	36,705
Prices	(U.S. dollars/metric ton)										
World reference price[y]	538	405	401	404	403	405	406	402	411	415	429
U.S. FOB Gulf long grain	532	425	422	424	424	426	427	423	432	437	451
U.S. No. 2 CA medium	780	596	584	595	600	598	599	592	582	583	579

[z] Total net exports are the sum of all positive net exports and negative net imports.

[y] Historically equal to the Thai100%B. However, for the projection period, this price equilibrates net trade and no longer corresponds to Thai100%B. Current Thai policies on domestic price, government storage, and government-to-government exports have limited its usefulness as a reference price.

Table 2. World rice supply and utilization.

	09-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	18-19	19-20
(thousand metric tons)											
Area harvested	152,530	153,747	153,739	154,261	154,444	154,761	155,209	155,293	155,309	155,377	155,676
(metric tons/hectare)											
Yield	2.85	2.91	2.93	2.93	2.95	2.96	2.97	3.00	3.02	3.05	3.06
(thousand metric tons)											
Production	434,730	447,696	450,514	452,302	455,223	457,768	461,701	466,272	469,625	474,055	476,681
Beginning stocks	92,410	90,660	94,004	96,393	96,307	94,477	93,683	93,018	93,073	92,724	92,681
Domestic supply	527,140	538,356	544,518	548,695	551,530	552,246	555,384	559,289	562,698	566,779	569,362
Consumption	436,470	444,352	448,126	452,387	457,053	458,563	462,366	466,216	469,974	474,098	477,622
Ending stocks	90,660	94,004	96,393	96,307	94,477	93,683	93,018	93,073	92,724	92,681	91,740
Domestic use	527,130	538,356	544,518	548,695	551,530	552,246	555,384	559,289	562,698	566,779	569,362
Trade	29,660	32,287	34,365	36,333	36,898	37,580	38,301	38,957	40,041	40,533	41,278
(%)											
Stocks-to-use ratio	20.77	21.16	21.51	21.29	20.67	20.43	20.12	19.96	19.73	19.55	19.21

Table 3. Per capita rice consumption of selected countries.

	09-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	18-19	19-20
	(kg)										
Argentina	8.0	8.4	8.5	8.5	8.6	8.6	8.7	8.7	8.7	8.8	8.8
Australia	14.8	14.7	15.2	15.5	15.5	15.5	15.6	15.7	15.7	16.0	16.2
Bangladesh	201.2	202.0	200.3	200.2	200.8	201.8	202.1	202.2	202.2	202.4	203.3
Brazil	43.5	46.0	45.8	45.6	45.4	45.3	45.2	45.2	44.6	44.7	44.6
Cambodia	266.1	266.3	267.2	269.7	272.0	274.0	275.9	277.7	279.2	280.7	282.0
Cameroon	17.5	19.1	20.5	21.2	21.4	21.4	21.6	22.6	22.7	23.0	23.0
Canada	10.2	10.6	10.8	11.3	11.8	12.2	12.6	13.0	13.2	13.5	13.7
China	92.4	93.0	93.0	92.5	92.2	91.4	90.3	89.8	89.4	89.2	88.5
Egypt	50.8	48.2	48.2	47.6	47.4	46.8	46.6	46.3	46.1	46.1	46.1
European Union-27	6.3	6.4	6.4	6.5	6.6	6.7	6.8	6.9	6.9	7.0	16.0
Ghana	21.2	21.4	21.0	20.4	19.5	18.5	17.9	17.6	17.7	17.7	17.9
Guinea	72.9	79.3	79.6	80.8	81.7	82.6	82.5	83.8	83.6	84.0	83.5
China - Hong Kong	49.7	53.7	54.0	54.3	54.6	55.0	55.3	55.8	56.0	56.3	56.4
India	76.8	77.9	77.8	77.9	77.7	77.7	77.6	77.7	77.3	77.3	77.1
Indonesia	155.7	159.1	157.7	158.0	157.5	157.2	157.7	157.8	157.6	157.1	157.2
Iran	54.2	55.2	55.3	55.7	57.3	56.7	58.0	59.1	59.1	60.0	61.2
Iraq	41.1	42.8	43.9	44.1	44.4	44.5	44.6	44.7	44.8	45.1	45.9
Ivory Coast	62.7	67.0	67.7	71.2	72.1	72.6	73.1	74.0	73.9	74.2	73.7
Japan	64.5	63.4	63.1	61.9	61.5	61.2	60.8	60.4	60.1	60.0	59.9
Kenya	7.6	9.5	9.5	9.6	10.2	10.3	10.6	11.1	11.3	11.6	11.5
Malaysia	95.1	98.1	97.9	97.5	97.9	96.6	96.9	97.0	97.2	97.7	100.0
Mali	71.3	76.2	76.7	76.7	77.4	78.0	77.9	78.7	78.5	79.4	79.4
Mexico	7.0	7.2	7.4	7.6	7.7	7.9	8.1	8.3	8.5	8.7	8.9
Mozambique	24.1	23.2	23.7	24.2	24.6	24.9	25.0	25.5	25.5	26.1	26.0
Myanmar (Burma)	184.4	184.6	184.6	184.5	184.8	184.7	185.0	185.2	185.4	185.7	185.6
Nigeria	34.2	36.0	36.1	36.4	36.6	36.7	36.8	37.1	37.3	37.5	37.6
Pakistan	14.9	16.7	16.9	16.9	16.9	16.8	16.8	16.8	16.7	16.7	16.6
Philippines	140.7	140.5	140.3	140.6	142.1	141.8	142.6	143.1	143.3	143.4	143.3
Saudi Arabia	45.3	46.9	47.4	47.9	48.4	48.8	49.3	49.8	50.1	50.5	50.8
Senegal	60.6	57.6	58.4	59.5	60.8	62.1	63.4	64.8	66.1	67.5	68.9

continued

Table 3. Continued.

	09-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	18-19	19-20
	(kg)										
Sierra Leone	115.8	122.3	122.3	121.7	122.6	122.8	122.4	122.9	122.7	123.3	123.0
South Africa	14.5	19.4	19.8	20.3	20.9	21.4	21.9	22.5	23.1	23.9	24.5
South Korea	102.6	102.0	101.0	99.7	99.0	97.4	95.8	93.8	93.7	92.3	93.0
Taiwan	47.5	47.5	47.6	47.6	47.5	47.7	47.6	47.5	47.2	46.9	46.6
Tanzania	22.8	25.3	25.5	25.9	26.5	26.7	27.1	27.8	27.7	28.0	27.9
Thailand	146.4	148.7	148.6	148.5	148.3	148.1	147.2	146.0	145.9	145.3	144.6
Turkey	8.4	8.3	8.4	8.4	8.4	8.5	8.5	8.6	8.7	8.7	8.8
United States	13.5	13.7	13.8	13.8	13.8	13.9	13.9	14.0	14.0	14.0	14.0
Uruguay	43.0	45.2	46.3	46.8	46.7	46.8	47.7	47.1	47.3	47.7	48.0
Vietnam	216.2	223.1	221.4	220.8	221.1	218.0	216.0	213.5	212.8	210.8	208.5
Rest of world	21.8	20.1	20.0	20.2	20.5	19.4	20.0	20.0	20.4	20.5	17.7
World	64.6	65.1	64.9	64.8	64.8	64.3	64.2	64.1	64.0	63.9	63.8

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